ENVIRONMENTAL FLOW ASSESSMENT OF THE LOWER COAL RIVER AND PITT WATER ESTUARY

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1. INTRODUCTION

1.1 Project background

This report describes a project designed to derive an environmental flow regime for the lower Coal River, southern Tasmania, downstream of Craigbourne Dam, and its estuary and related coastal embayment, Pitt Water.

Within the current Tasmanian water management policy context, the principle aim of an environmental flow regime is to maintain existing values. This implies a focus on existing conditions. However, opportunities for environmental rehabilitation/ restoration should also be explored where they are broadly commensurate with the existing water management focus, which in the lower Coal is on irrigation water supply.

The Coal catchment has been extensively cleared for grazing, and development for intensive agriculture has been stimulated by the development of irrigation infrastructure. This development has had a number of consequences for the Coal River and Pitt Water, whose environmental condition is discussed in Sections 2-4 of this report.

Table 1.1. Coal River catchment attributes, and how they compare to Australia-wide values (for those areas covered by the National Land and Water Resources Audit). Source, NLWRA 2000.

Attribute	Unit	Basin value	Median Australia-wide value
Basin area	km^2	684	7208
Improved pasture	%	17.56	1
Cropping	%	0.98	0
Horticulture	%	5.61	1
Total agricultural land proportion	%	24.15	7
Climate			
Rain	mm/y	560	860
Total evaporation	mm/y	406	584
Runoff	mm/y	154	249

1.2 The Existing Flow Regime

1.2.1 Historic changes in the Coal River catchment.

Agriculture is a major activity in the Coal River catchment. This region was originally developed in the late 1800's for wheat growing and expanded to include wool, fat lambs, beef and cropping of oats and barley after World War II. However, expansion of agriculture in the region was limited by availability of water. To overcome this shortage and ensure reliability of flows, the Craigbourne Dam was constructed in 1986 as part of the South-East Irrigation Scheme. With the advent of reliable flows of water, agriculture in the region has changed to include many high value crops, including a variety of vegetables and herbs, poppies, turf, pyrethrum, wine grapes, intensive pig and poultry industries and specialist seeds. The estimated population of the catchment is 2500 people (Daley 1999).

The Coal River and associated flood plains and riparian zones have been extensively modified since European inhabitation (Coal Rivercare Plan, unpublished report for the Coal Valley Landcare Group). Extensive vegetation clearing occurred following early settlement and into the early 1900's (Daley 1999). Changes in land cover were quantified between 1965 and 1997 Daley (1999). These changes were mostly small, but numerous and widespread. In particular, forest cover had decreased by approximately 34 km^2 (6%), especially in the upper catchment, and become more fragmented, whereas grassland had increased by about 20 km^2. However, from an assessment of catchment flows and evapotranspiration rates, the effect of recent change in land coverage on flow in the Coal River was estimated to be minor.

Although flow from Craigbourne Dam is regulated, the exact amount extracted for irrigation is not known because of the large number of small dams and direct pumping from the river. The number of registered instream and offstream dams in the Coal River catchment is approximately 300, with a potential capacity of 35,500 ML, including Craigbourne Dam.

Flow has been measured for varying periods at six flow gauging stations in the catchment during 1965-1997 (Daley 1999). It was measured above Craigbourne Dam at Baden from July 1971 to present, at Craigbourne Road from July 1961 to January

1981, at the Dam since it commenced operation in October 1986, and below the Dam at White Kangaroo Rivulet from July 1963 to August 1993. Flows in the lower section of the catchment have been monitored in relation to water extraction at Creeses Weir above the Richmond Bridge and at 150 m upstream of the Richmond Weir, from June 1989 to December 1993. They have also been monitored at the Richmond Weir downstream of the bridge from June 1989 to present. Management of the Craigbourne Dam became the responsibility of the South East Irrigation Scheme in 1993. All currently operating flow stations in the Coal River catchment, except Baden, monitor flow for irrigation purposes. Thus there are no accurate records of natural flow for the lower catchment since the commencement of the South east Irrigation Scheme.

Daley (1999) found that flows were highly correlated between White Kangaroo Rivulet and Baden, while it was operating; however they were not significantly correlated between the irrigation dam stations at Craigbourne Dam, and at Creeses and Richmond weirs. Flows at Richmond and Creeses Weirs were low, compared with the other stations, and indicated that only a small proportion of the flow was reaching the lower parts of the catchment. A comparison of annual rainfall with indicative annual flows for the catchment showed that during periods of high rainfall and flood conditions, river flows corresponded well with rainfall, regardless of whether the river was dammed or not. However, during lower rainfall periods and especially after 1987 and the advent of the irrigation scheme, this correlation is not as high.

1.2.2 Changes in the Flow regime

The natural flow regime of the Coal River (prior to flow regulation by Craigbourne Dam) was characterised by:

- Very low summer-autumn flows, supplemented by ground water contributions, though with occasional cessation of flow events;
- Higher, continuous winter-spring baseflows;
- Flood and high flow events during winter-spring, and occasional later spring – early summer floods, all highly variable in magnitude and timing both within and between years;

- highly variable flows between months and years.

Changes in the natural flow regime following successive phases of land clearing, coupled with indirect (eg farm dams) and direct (eg pump outs) abstraction of water, would have resulted in significant changes to both the pattern of high and low flows in the Coal River prior to Craigbourne Dam.

The Coal River now has a highly regulated flow regime, largely due to the presence of Craigbourne Dam (storage 125 000 ML). Water is released from the dam for direct abstraction from the downstream channel by irrigators between Craigbourne and Richmond in the Stage 1 area of the SEIS (Barrett Purcell & Associates Pty Ltd 1995). Between 1991 and 2001 a pumping station at Richmond also served to irrigate areas in the Stage 2 area around Richmond, Middle Tea-Tree and Campania. The construction of the Daisy Bank Dam to feed water pumped from Hobart's Water supply into the SEIS ended the pumping from Richmond (DPIWE 2001). When operating, the Richmond pumping station also contributed to the modification of the Coal River flow regime.

Since Craigbourne Dam has been operating, substantial changes in the timing and magnitude of both high and low flows have occurred, primarily in response to storage and delivery of irrigation flows. This, coupled with highly managed abstractions at several locations downstream of the dam and the management of weirs, has resulted in a highly altered regime, both within the river and at the upper end of the estuary.

Water abstractions from the Coal River for irrigation, stock watering, or domestic purposes downstream of the dam are numerous along the river in the study area. The total number of individual abstraction points and quantity of water being abstracted is not precisely known, and their individual effects on the hydrology and subsequently the river geomorphology cannot be fully quantified.

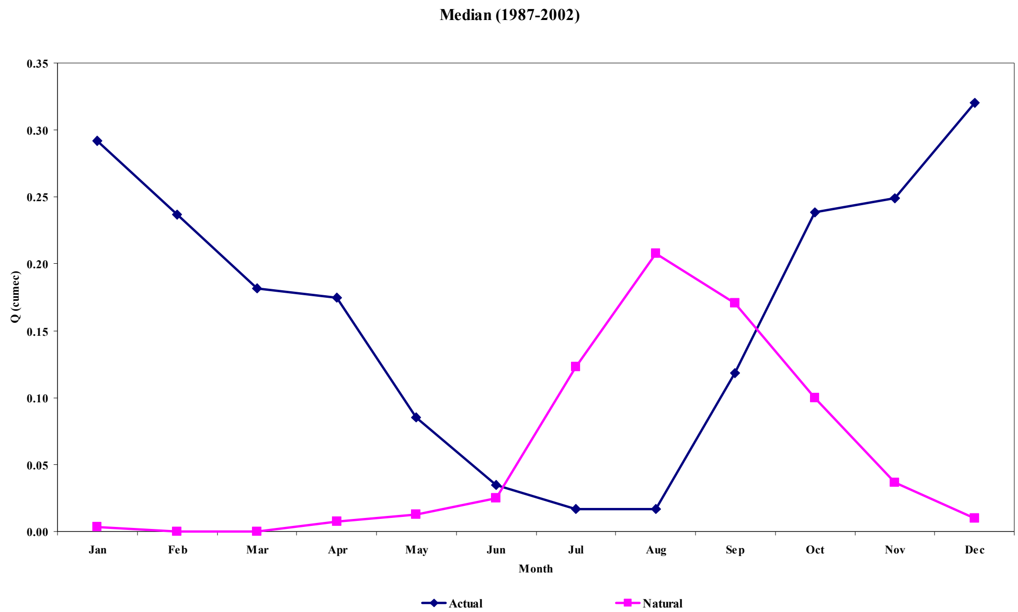
Figures 1.1 and 1.2 show a reversal in the natural seasonal pattern of flow under current conditions, which is particularly strong immediately downstream of Craigbourne Dam (Mt Bains, Fig 1.1). Lower catchment inputs provide a small winter-spring peak in the lower Coal (at Richmond, Fig. 1.2), though this is absent in drier years. The current flow pattern is of higher summer-autumn baseflows, as controlled irrigation releases, also shown in the flow exceedance curves (Figure 1.4). Minimal or no dam releases occur in winter-spring, resulting in zero flow immediately downstream of the Dam, and some supplementation from tributary inflows downstream, unless major flooding occurs.

The current flow regime is characterised by a substantial reduction in the magnitude, frequency and duration of high flow events (Figures 1.3, 1.4). Despite some tributary inputs, the entire length of the Coal downstream of Craigbourne Dam is characterised by a significant reduction in floods over a range of sizes compared to the natural flow regime. Hydro Tasmania (1995), in a report on flood sequences in the lower Coal, compared sizes of floods of given exceedance probabilities with and without Craigbourne Dam being present. The 1 in 2 year and 1 in 10 year annual exceedance floods at Richmond are reduced by around 33% in magnitude. For the 1 in 5 year flood which occurred previously without the Dam, the return interval is now around 1 in 8 years.

There are limited runs of flow data collected regularly at time steps of less than a day. Initial examination suggests that rapid fluctuations in level occur in response to dam operations, and some pumped abstractions.

Overall, the existing flow regime in the Coal River is characterised by:

- Highly regulated flows;
- Loss of the natural seasonal pattern;
- High baseflows during summer-autumn;
- Reduced baseflows during winter-spring;
- Reduction in flood size, frequency and duration;
- Rapid level changes over periods of hours associated with irrigation water delivery.



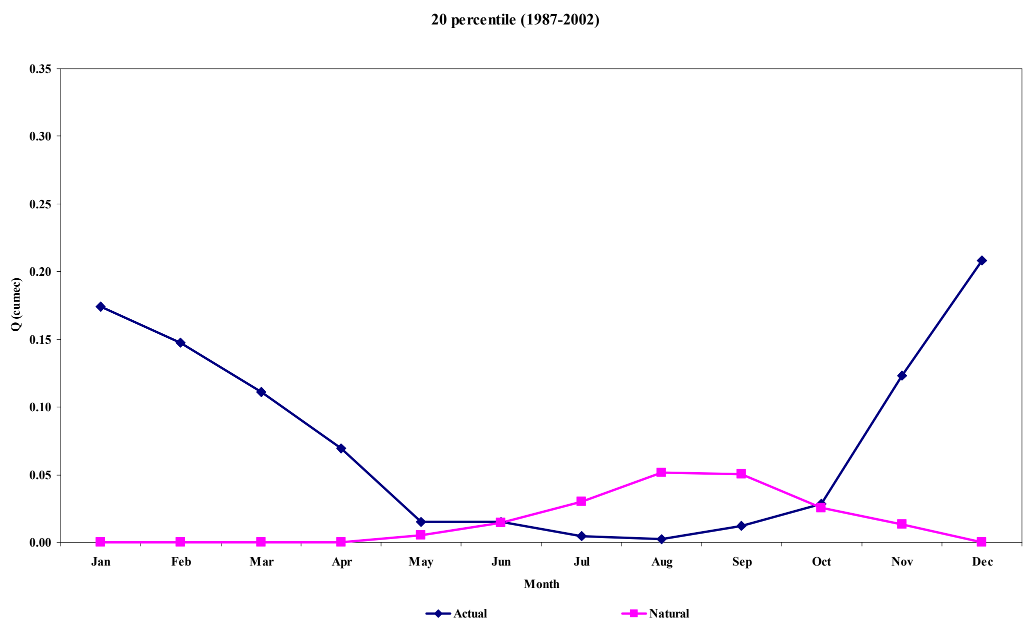
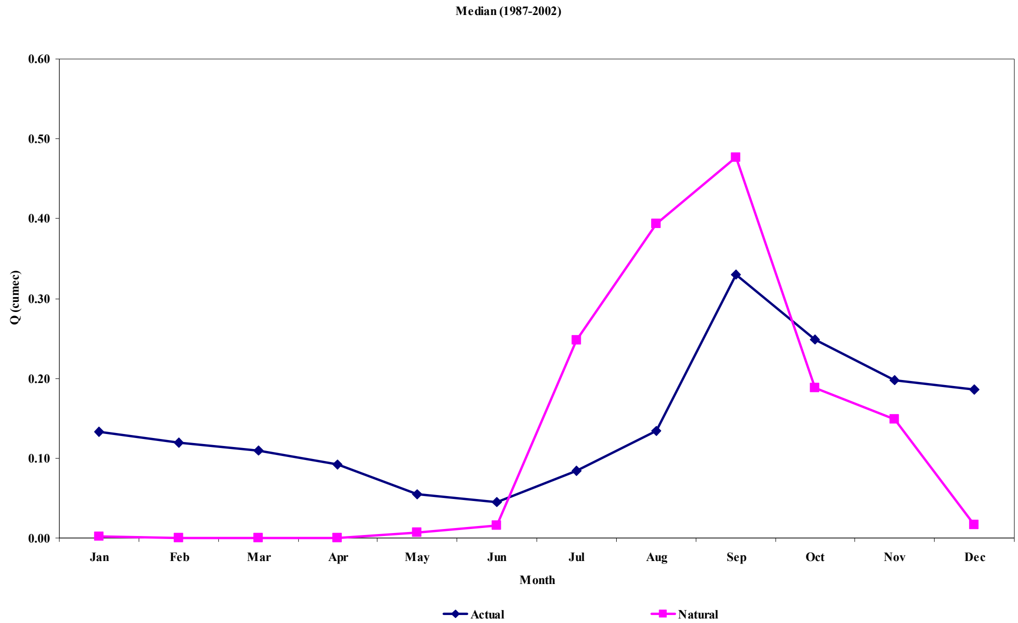


Figure 1.1. Seasonal pattern of mean daily flows, by month, as monthly median and 20 percentiles, in the Coal River at Mt Bains (downstream of Craigbourne Dam) between 1987 and 2002. Data supplied by D Fuller (DPIWE), and based on modelled relationships between pre-dam flows and unregulated flows at Baden. Flows in cumec (cubic metres per second).



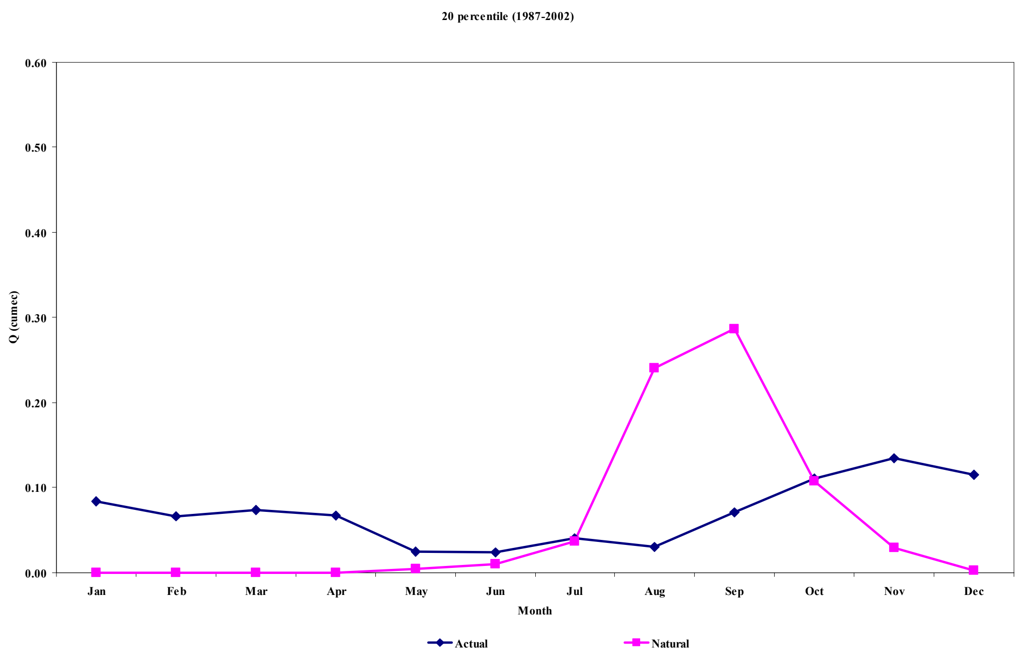


Figure 1.2. Seasonal pattern of mean daily flows, by month, as monthly median and 20 percentiles, in the Coal River at Richmond Weir between 1987 and 2002. Data supplied by D Fuller (DPIWE), and based on modelled relationships between pre-dam flows and unregulated flows at Baden. Flows in cumec (cubic metres per second).

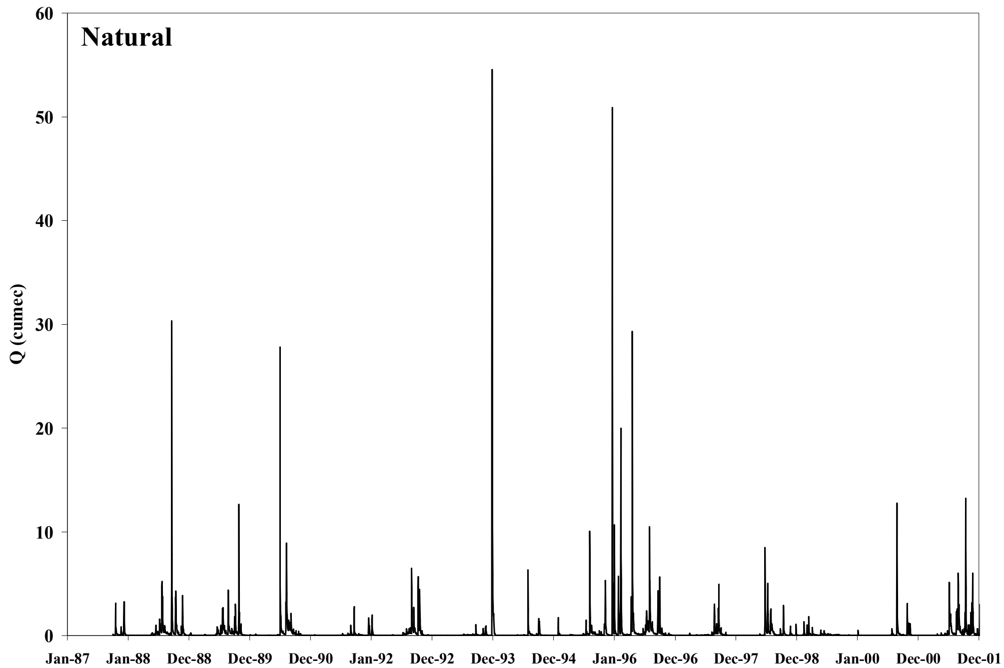


Figure 1.3. Comparison of natural (modelled) and actual (historical) flows in the Coal River at Mt Bains between 1987 and 2001. Data supplied by D Fuller (DPIWE), and based on modelled relationships between pre-dam flows and unregulated flows at Baden. Flows in cumec (cubic metres per second).

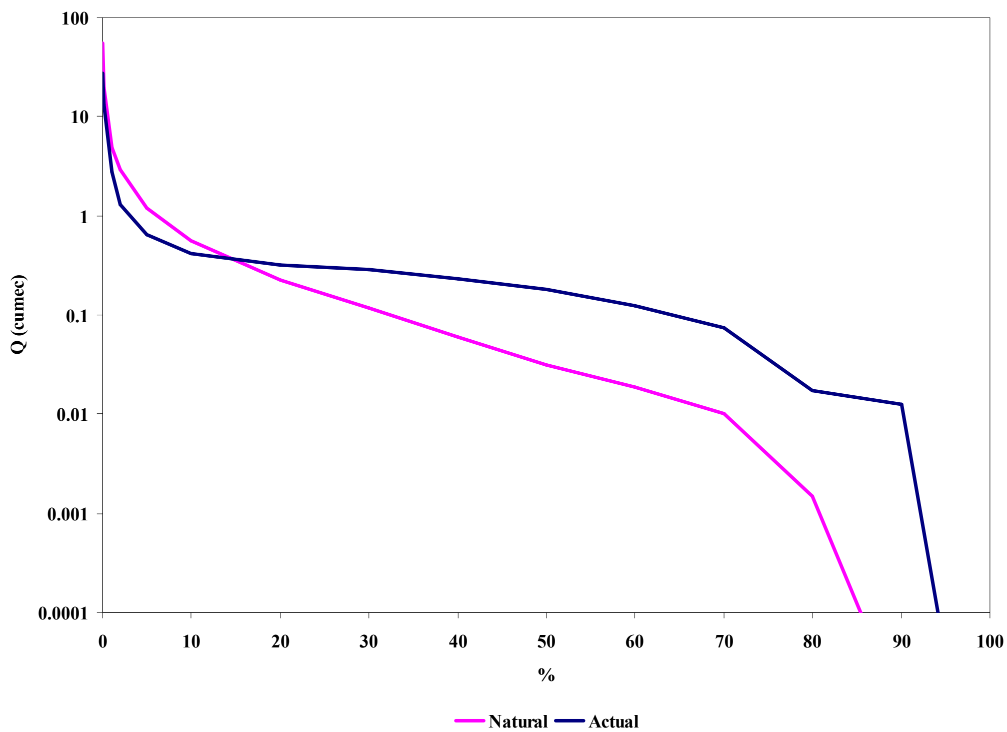


Figure 1.4. Exceedance plot of mean daily natural (modelled) and actual (historical) flows in the Coal River at Mt Bains between 1987 and 2001. Note log discharge scale. Derived from data supplied by D Fuller (DPIWE), and based on modelled relationships between pre-dam flows and unregulated flows at Baden.

These characteristics of the flow regime are also imposed on the estuary. However, baseflows into upper Pitt Water are likely to be much lower than shown in Figure 1.2 due to the presence of an ungauged weir downstream of the Richmond Weir. Abstractions from this weir are unquantified and are believed to cause reduction and occasional cessation of flow at estuary head during summer-autumn. Thus the estuary is also affected by a further, unquantified reduction in overall water delivery during the irrigation season.

The environmental affects of the changes in flow regime in the Coal River and Pitt Water are discussed in subsequent sections of this report.

1.3 Environmental values and assets

Little is known about the current ecological condition of the Coal River system, despite a number of reports describing possible management plans and development options (Gallagher 1997, Ecosynthesis 1999, DPIWE 2001). This project therefore provides an overview of the current environmental condition of the Coal River, and the Pitt Water estuary. The highly modified nature of the aquatic ecosystem, and its loss of natural values, is of concern and makes the focus of management through environmental flows alone problematic. This is discussed in detail in later sections of this report.

1.4 Environmental Flow Regime

For the purposes of this report, the assessment of environmental flows incorporates the concept of an **environmental flow regime** which includes all major aspects of the pattern of flows required to maintain the riverine and estuarine ecosystems and associated values. An environmental flow regime includes both:

- the magnitude and seasonal pattern of minimum flows or baseflows; and
- the magnitude, timing and frequency of high and flood flows.

The inclusion of a range of key flow types within an environmental flow regime, and not just a minimum environmental flow, is now seen nationally as vital to the maintenance of riverine and estuarine systems.

Minimum or baseflows are important in the protection of key habitats and refuges for instream biota, as well as for maintaining core ecosystem processes such as primary production along the channel centre-line. A seasonal pattern in baseflows is important to allow seasonal patterns of growth and recruitment of aquatic plants to be maintained, to allow access to specific habitats associated with key aspects of fish life cycles (eg spawning substrates, backwaters for juvenile fish) and to allow seasonal wetting and drying of organic material and sediments.

High flow and flood events are vital for maintaining key geomorphological and biological aspects of river systems. High flows are key determinants, within a local geological setting, of channel form, sediment characteristics and sediment transport. Flood flows act as triggers for fish migration and spawning, transport organic material through the drainage system, transport and flush sediments both within the river and to the estuary, serve to maintain and structure riparian vegetation communities.

The pattern of flood flows also is a key driver of estuary geomorphology which is largely determined by the balance of river-flood driven sediment inputs and coastal-tidal sediment transport. Shifts in this balance can lead to major changes in estuaries related to infilling with riverine sediments and/or scouring due to sediment starvation. Many key estuarine biological processes are also driven by or linked to the pattern of delivery of flood flows and associated pulses of nutrients.

1.5 Project approach

This project and report follows the following framework (Table 1.2), adopted from the Victorian government FLOWS approach (SKM, DNRE unpub. report). This methodology contains most of the elements and approaches currently being used to define environmental flows for Tasmanian rivers (e.g. Davies et al. 2001, Davies and Warfe 2002). It has the advantage of having a clearly articulated procedural framework which articulates environmental flow management objectives and identifies specific aspects of the flow regime which can be used to achieve, or partially achieve, those objectives. This study does not follow the FLOWS methodology, merely the project design framework. Key elements of the environmental flow regime are identified using techniques already used or being trialled in other Tasmanian environmental flow assessments (Davies et al. 2002, Davies and Warfe 2002, DPIWE X?).

Table 1.2. Steps used in defining an environmental flow regime for the Coal River and Pitt Water, and the corresponding report sections.

Steps	Report Sections
Describe environmental condition of Coal River and Pitt Water	2-5
Identify key environmental values and assets in the Coal River and Pitt Water	6
Describe main environmental objectives that can be linked to the flow regime	7
Describe the key flow elements/processes needed to meet each objective	8
Identify key flow components	9
Describe final environmental flow regime	10
Recommend overall environmental flow management	11

The first step in identifying an environmental flow regime is defining the **aims and objectives** of establishing environmental flows, as well as identifying the **values and assets** the objectives are tied to. It is important to identify management objectives that can be directly tied to environmental flow management, since many environmental outcomes cannot be achieved by flow management, especially in river-estuarine systems heavily affected by land clearing and poor water quality.

An assessment of the **environmental condition** of the river system must be conducted, focussing on key values/assets. This can be collated from existing literature and/or data, but in the absence of good background information usually involves some form of dedicated survey and interpretation. The lack of good background information on the biota, geomorphology and overall environmental condition of the Coal River and Pitt Water system was surprising. Limited time and resources available for this project has prevented a detailed assessment, which will only be partially rectified by the DPIWE State of the Rivers report. Specific recommendations for further assessment in key areas (eg estuary geomorphology) are made in the final sections of this report.

Specific aspects of the flow regime – **key flow elements or processes** - must be identified which can support or influence the achievement of each environmental objective. These are then reduced to a set of **flow components** which are put together to form the **final environmental flow regime** of the system. This requires integration of flows needed for the river and estuary.

2. ENVIRONMENTAL CONDITION – COAL RIVER GEOMORPHOLOGY

This chapter provides an assessment of the state and history of fluvial geomorphology of the Coal River, and of the effects of flow regulation, as background to the environmental flow assessment.

2.1 Geomorphology

2.1.1 General Description of the Lower Coal River study area

To conduct a geomorphic assessment of the Lower Coal River, it is necessary to consider the study area within the context of the broader river system. The catchment of the Coal River covers 630 km^2 and lies just to the northeast of Hobart and approximately parallel to the Jordon River catchment. The headwaters of the Coal River rise in the hills east of Tunnack at an elevation greater than 520m. The catchment generally lies in a north – south direction, with the headwaters initially flowing north, swinging to a westerly flow near Baden before flowing south down to the Pitt Water estuary.

The study area of the Lower Coal River extends approximately 35.2 km from immediately below the Craigbourne Dam to the second weir approximately 1 km downstream of the Richmond Bridge, which marks the upper boundary of the estuary (Figure 2.1). The elevation drop along this stream length is in the order of 150 m to sea level. Approximately half the catchment area (247 km^2) of the Coal River is above Craigbourne Dam.

In the upper catchment, the river runs through a deeply incised gorge and then flows into the Craigbourne Dam just southeast of Colebrook. Below the dam, the river continues down through a series of floodplains and minor gorges to the Pitt Water estuary. The Pitt Water estuary is a RAMSAR site of international significance. The estuary consists of an ocean embayment, which opens out into Frederick Henry Bay via a channel at the southern end of Seven Mile Beach. The major tributaries entering the Coal include the Wallaby Rivulet (approximately 82 km^2 catchment area), which flows into the Craigbourne Dam, the White Kangaroo (approx. 96 km^2) and Native Hut Rivulets (approx. 44 km^2), which both enter below the dam within the study area.

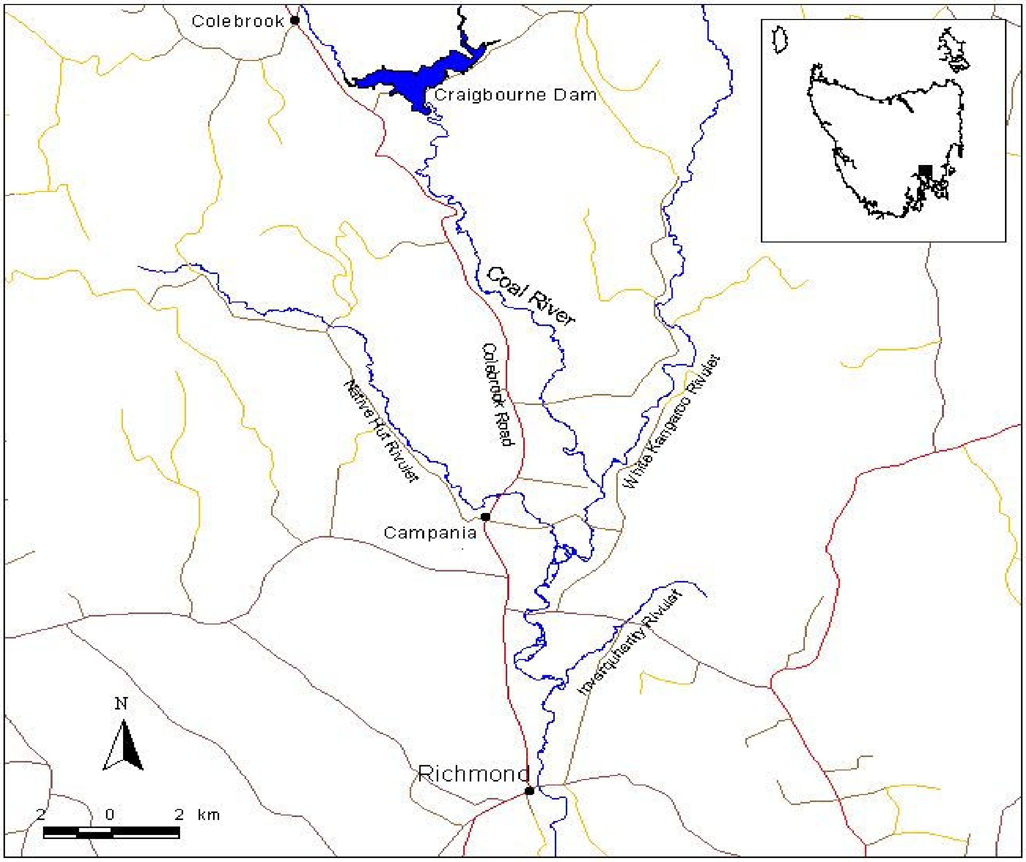


Figure 2.1. Lower Coal River Study Area

Various studies have been conducted on the geology of the catchment (Figure 2.2), but little has been documented on the geomorphology of the Coal River system. The present river course generally follows the length of a down-thrown block or graben that formed during episodes of faulting in the Jurassic and early Tertiary periods. Permian mud, silt and sandstones, Triassic sandstones, and intrusive Jurassic dolerite underlie the valley. Tertiary Basalts and river and lake sediments fill parts of the lower Coal valley, and Quaternary alluvial and aeolian sediments form the majority of the river floodplains and lower terraces. Hills and ridges of dolerite border the lower river valley reaching heights greater than 560m along with lower Basalt plateaus (approximately up to 120m). Triassic sandstone dominates the hills along the valley in the upper catchment reaching elevations between 400 and 500m.

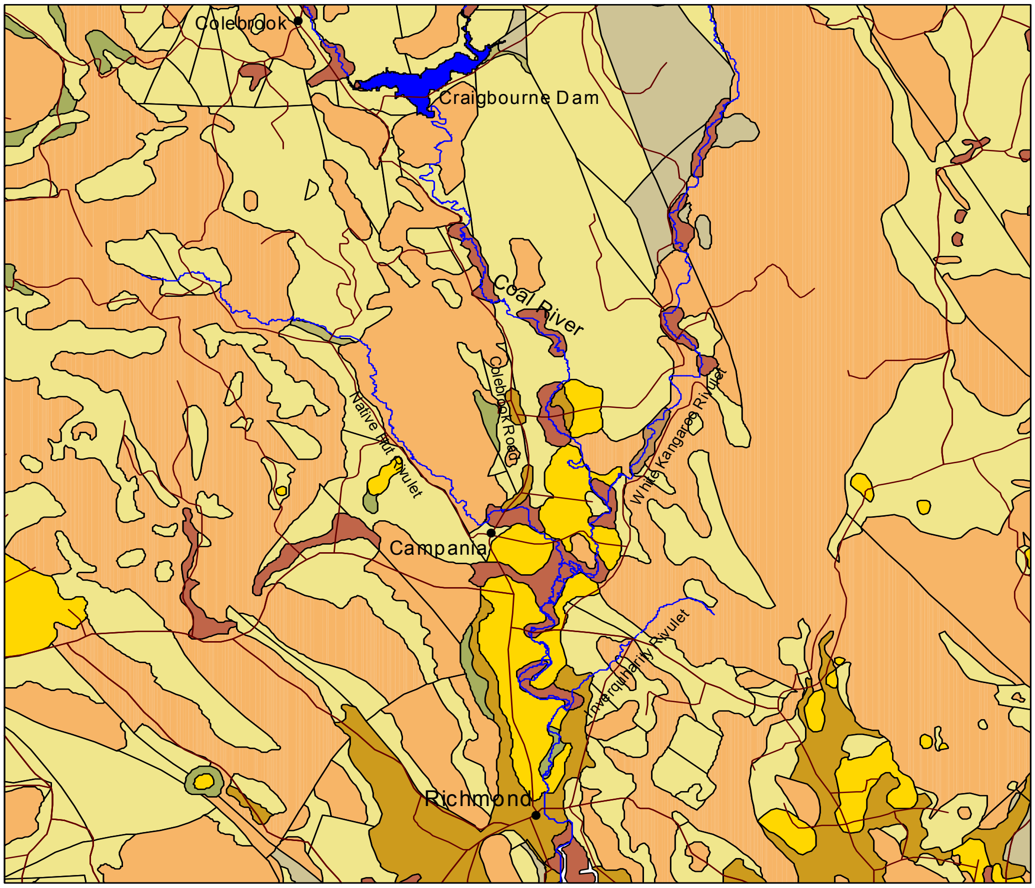


Figure 2.2. Geology of the Lower Coal River Study Area

The natural vegetation throughout the catchment and within the study area has been subject to a long history of modification by land use practices, beginning when the Coal River valley was settled in the 1820's. In response to these practices, various exotic plants including, crack willow, gorse, boxthorn, hawthorn, cumbungi and introduced pasture grasses, have replaced a great deal of the natural riparian vegetation.

Daley (1999) reviewed the landuse history of the Coal Valley. The area had become a major wheat growing area by the middle of the 19th century. The dominant land use in the catchment continued to be cropping until the 1930's and sheep and cattle grazing became more pronounced after World War II. Agriculture slumped in the 1960's and the 1967 bush fires caused substantial damage to areas of the catchment. Pressure for increased water availability for farming mounted in the 1970's and led to the development of the South East Irrigation Scheme (SEIS). Agriculture subsequently intensified, introducing new cropping and animal grazing enterprises and expanding existing ones.

Daley noted that the first official awareness of the effects of these landuse practices occurred in 1967, and included such problems as soil structure decline, tunnel and gully erosion, an increase in annual and perennial weeds, salinity, and frequent flooding as a result of crack willow infestation. A review of more recent research into the susceptibility of land systems to erosion, and soil and land degradation on private freehold land within the Coal valley catchment has been conducted by Gallagher (1997). Areas are highlighted that are potentially subject to gully erosion, tree decline, mass movement, tunnel erosion, wind erosion, sheet and rill erosion, soil structure decline, streambank erosion, flooding and waterlogging. A land capability survey has also been conducted (Musk and Rose 2000) that provides information on the erosion risks to soils in the catchment including those on valley floors and floodplains and alluvial plains. The above processes can significantly influence the fluvial geomorphology of the Coal River and the sediment loads being transported to the Pitt Water Estuary. It is almost certain they have done so in the past, and probably continue to do so, but there are no apparent studies that provide direct links.

An assessment of the effects of land cover changes between 1965-1997 on the Coal River flows have been related to small changes measured in the flow (Daley 1999). However, some of the effects may have been masked by the impacts of the Craigbourne Dam construction and increased irrigation abstractions during this period. Aerial photographs depicting the Lower Coal River before the dam (1946) were examined in this study, and revealed channel and tributary incision, artificial channelisation, drainage and/or irrigation works on floodplains, the presence of several instream structures (weirs and fords), a lack of native riparian vegetation on alluvial sections, willow infestation, and some areas of natural recovery from incision. The current Lower Coal River exhibits these features, but their occurrence in 1946 suggests the river flow and sediment delivery has been subject to significant impacts by landuse practices and river management since well before the present.

The hydrology of the Coal River is generally perennial in nature with intermittent or ephemeral tributaries entering the trunk system. A great deal of the meteoric recharge to the groundwater overflows as springs and seeps to creeks and rivers. There is little retention time as the watertable is generally continuous and unconfined, and often lies very close to the ground surface (Leaman 1971). As a result, the Coal River is subject to considerable groundwater input.

The hydrology of the Coal has been highly modified (see Section 1.3), as it is now regulated by Craigbourne Dam.

2.1.2 Evolutionary history of the Lower Coal River

To assist with the interpretation of the present-day geomorphic features of the Coal River, an understanding of the evolutionary history of the Coal valley is important. Landuse and river management practices since European settlement have significantly affected the present-day condition of the river, but it is the underlying evolutionary factors that have directly influenced the broader form of the Coal River and the processes by which the river has developed. This discussion provides a basis for explaining the differences in the present day geomorphology of the river that may contribute to contemporary responses to land and river management.

The development of the present-day Coal River was significantly influenced by two periods of block faulting during the Jurassic (205.7-142 million years before present) and early Tertiary (65-1.8 mybp) periods. Fish and Yaxley (1966) and Leaman (1971) suggest that Triassic (248.2-205.7 mybp) sandstone sheets and Permian (290-248.2 mybp) mud, silt and sandstones were shifted, and dolerite intruded into the landscape during the Jurassic period. The Richmond Graben (a down thrown block between two faults) was formed. It is likely that subsequent faulting in the early Tertiary period continued to warp and fault these structures. The graben and fault lines, in combination with the erosion-resistant dolerite, have generally controlled the Coal River drainage system since that time.

Subsequent to the faulting in the early Tertiary, sediments were deposited in a series of basins (Penna, Richmond-Campania, Pitt Water and Seven Mile Beach), two of which Leaman (1971) concluded were joined by a deep narrow ravine, suggesting a valley system existed that was controlled by the uneven floor of the graben. Several episodes of volcanic activity that were separated by periods of erosion and sedimentation (Holz 1987), resulted in approximately 15 basalt extrusions along the fault lines, which altered the drainage pattern of the river system (Leaman 1971). Within the study area, the basalt forms the upper river plain surface between Richmond and Campania, and it continues to control sections of the present day Coal River. A layer of sandy alluvium overlying the basalt terrace can be observed at Nugent and occurs in many other areas of the broader river valley (Holz 1987).

It appears that the basalt filled parts of the former valley, displacing the original river course in some reaches through the less erosion-resistant Triassic sandstone. Where the river encountered the more erosion-resistant dolerite it was forced to incise the basalt, forming relatively deep gorges. This is probably the cause for the basalt gorge that controls the present day Coal River between Cranston (south of Brown Mountain Road) and Penrise (above the confluence with White Kangaroo Rivulet). Where the basalt flow was relatively thin, however, it is likely the original drainage pattern incised down through the basalt. Two exposures of the thin basalt sheet can be observed in the section of the present day Coal River above Richmond where the basalt overlies Tertiary sediments, which have both been incised by the river (eg. at St John's Church cemetery and approximately 1.3 km upstream of the Richmond Bridge).

After the Tertiary period, the Quaternary period (1.8 mybp – present) was distinguished by several periods of glaciation and fluctuating sea levels in response to the changes in climate (glacial vs interglacial). The sediment deposition in the Coal River system would have been high during glacial periods when periglacial processes in upland areas provided large sediment loads to the lowland river systems. The presence of aeolian sand deposits on the eastern side of the Coal River support this, as they would have required a sufficient source of sand on the floodplains that could have only been deposited during periods of severe flooding and increased stream competence and blown during dry windy periods, which are typical of periglacial conditions (Fish and Yaxley 1966).

When the climate was warmer during interglacial periods, vegetation stabilized the sediment sources to the river system, which resulted in the erosion of lowland areas. The landscape response to these fluctuating periods of deposition and incision, combined with the geology of varying degrees of erosion resistance, led to an array of elevated terraces being formed throughout many reaches of the lower Coal valley. Sea level changes may have also influenced the creation of some terraces when base levels altered (Fish and Yaxley 1966, Leaman 1971).

The cessation of the last glacial period, approximately 12 000 years ago, led to a general decrease in sediment deposition and increased incision in the Coal River system. Some finer deposits are apparent in the modern floodplains dating to the mid-Holocene epoch (Holz 1987). Other younger layers of sands and gravels on the modern floodplains have probably been deposited since European settlement with accelerated catchment erosion due to various catchment land practices (Holz 1987). Variation in the composition of these modern floodplains and older terraces results in different levels of susceptibility to fluvial and mass movement erosional processes. Episodes of increased catchment runoff resulting from land clearance are also likely to have contributed to the incised nature of the present day river.

2.1.3 Geomorphic Characterisation

The underlying geomorphic factors of a river system control the river's character and behaviour, and influence it's response to natural events like flooding and anthropogenic effects of landuse and river management (Brierley et al 1996). These factors include the geology; channel gradient; valley width and floodplain development; terrace presence and composition; degree and type bedrock intrusion into the channel; channel morphology and features (eg. riffle/rapid substrate and form, and deposition features like bars); dominant erosional processes; and riparian vegetation associations. Where these factors alter along the river length, the river character, behaviour and subsequent river responses to natural events and anthropogenic influences also change. It is therefore useful to characterize the river into relatively homogeneous zones to enable the prediction of the river's response to potential changes in the management of the flow regime.

The Lower Coal River has been separated into 10 sequential geomorphic zones that are generally based on the above parameters. Due to little change in the gradient of the river throughout the study area, channel gradient has been precluded from the characterization (Figures 2.3 and 2.4). Like any classification, there is still diversity and variation within each zone, and the boundaries between zones are not always clear, but the differences between the zones are considered to be greater than those within each.

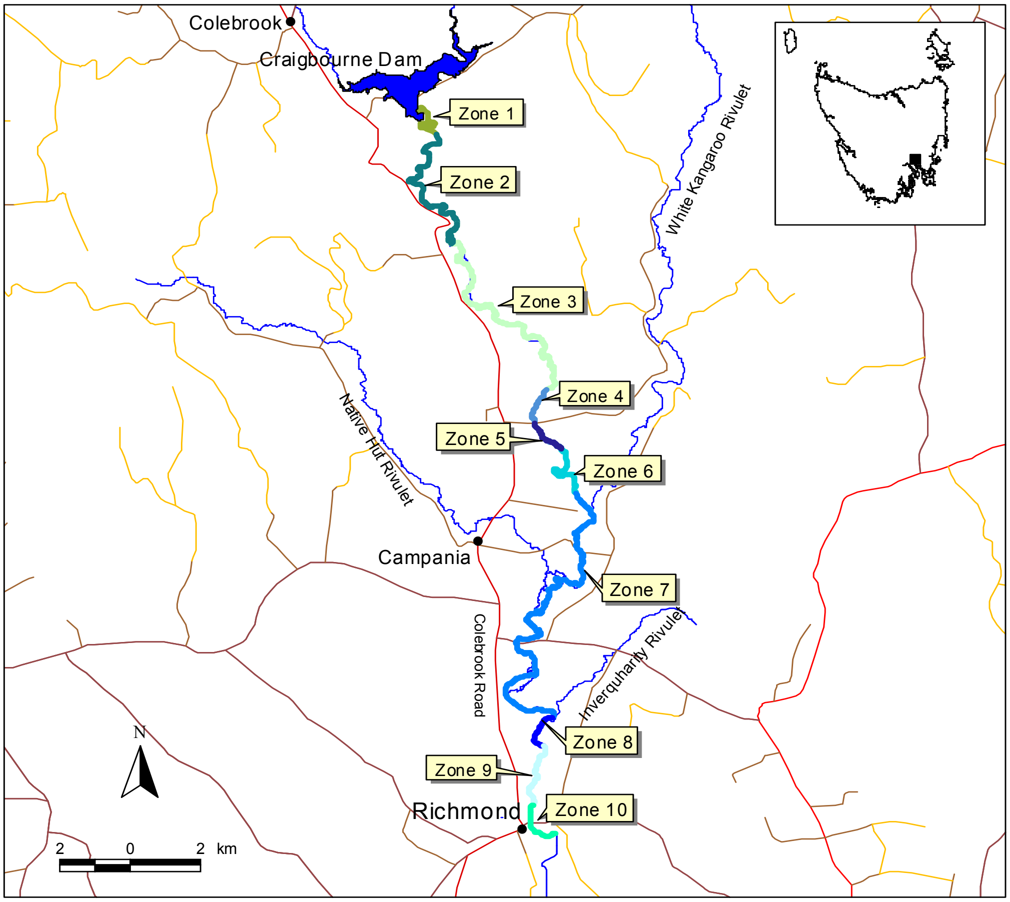


Figure 2.3. Geomorphic Zones of the Lower Coal River Study Area

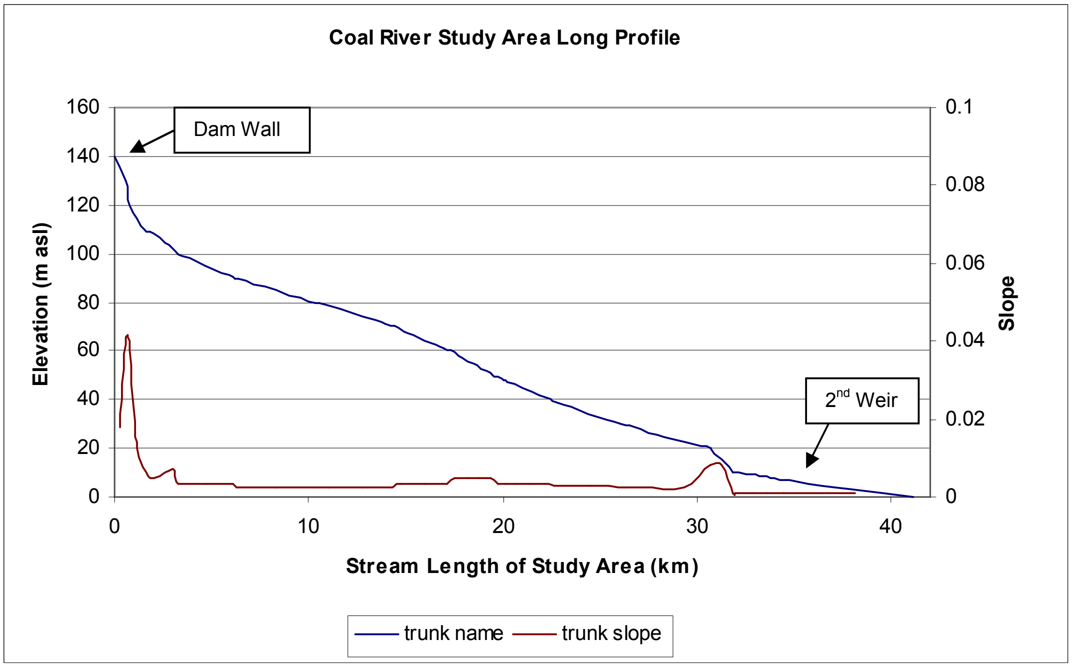


Figure 2.4. Long profile and of the Lower Coal River Study Area

Zone 1 Confined Dolerite Gorge

Zone 1 is located directly below Craigbourne Dam and extends downstream for approximately 1.8 km. The river channel is entrenched in dolerite bedrock, forming a narrow V-shaped valley with steep sides. The bedrock controls the river banks and bed, indicating an inherently stable zone that is highly resistant to geomorphic change.

The hydrology is determined by the regulated flows from Craigbourne Dam as no major tributaries enter the river in this zone. The zone is predominantly a sequence of bedrock and cobble bars, riffles, runs and some pools. Minor discontinuous floodplains are present and some benches have developed on the sides of the channel where exposed bars have been colonized by vegetation (eg. crack willow, macrophytes and gorse). The vegetation acts as silt-trap for any colluvial material from the gorge slopes and/or alluvial silts from the small intermittently flowing tributaries that drain the surrounding cleared hill slopes. Very little sediment would be making it through or over the dam. This zone is considered, however, to have a greater sediment transport capacity.

The riparian zone has been considerably modified by landuse practices and consists of a dense gorse understorey with semi-mature willows that have invaded the remnant native woodland vegetation (eg. wattle and eucalypts) and encroached upon the channel (refer to Ecosynthesis 1999, for more detailed riparian habitat information).

Figure 2.5. Zone 1 gorge entrenched in dolerite.

Zone 2 – Sandy alluvial floodplains with partly confined dolerite and sandstone

The valley opens out below Zone 1 to a slightly broader valley, where three minor intermittent tributaries enter the trunk system. It is considered that these tributaries and others that enter the Coal River throughout this zone have no significant impact upon the hydrology of the trunk system, which continues to be dominated by the regulated flows released from Craigbourne Dam.

A sequence of Quaternary alluvial floodplains and terraces begin to develop, which vary in width according the degree of confinement by dolerite or sandstone bedrock valley walls. A minor gorge appears to be holding up the first set of floodplains, but otherwise, the floodplains generally overlap between reaches along the approximately 6 km length of this zone. They are composed of a well drained sandy alluvium including a young sandy layer, probably deposited since European settlement, overlying an older soil profile of harder sandy clay A and B horizons. Soil mapping (Holz 1987) indicates this zone has a well-drained, medium-fine textured soil (Stockdale) that has developed on floodplains of Holocene age and is prone to erosion during floods.

Elevated Quaternary alluvial terraces occur with shallow abandoned channels and natural levees. The terraces consist of large quantities of sandy alluvium of medium coarseness, which suggests an old alluvial fan deposition by a more enegetic river system in the past. A terrace of eroded sandstone bedrock also appears near the bottom of this zone, which would be more resistant to erosion than the alluvial terraces.

The river is a riffle and pool sequence, and sandstone bedrock intermittently exerts a minor stabilising control on the river bed and banks. Riffles consist of cobbles overlying sandy gravels or instream willows, particularly in the lower half of the zone. A hard sandy clay (probably the old B horizon observed upstream) substrate is apparent within several of the pools. Cobble riffles in the upper section of the zone have a slight armoured appearance. Some headcuts are present and localized bed degradation is apparent where a more sandy gravel substrate occurs in scour pools below willow riffles.

The current river channel has incised through the terraces and floodplains with some evidence of scour on the terrace banks, and localized scour on the current channel banks. Some incision at the entrance of minor tributaries to the trunk system is also present. A few abandoned channels choked with willow, are present where the current channel has avulsed in the past (possibly in response to the vegetation choked channel). Modern benches and small islands have formed within the broader channel, which are colonized by vegetation including willow, grasses, macrophytes and other exotics like gorse (refer to Ecosynthesis 1999 for more detailed riparian habitat information). The localized scour of the present channel banks appears to be in association with the deflection of flow by instream vegetation (including the vegetated benches and islands) onto cleared banks that are more prone to scour.

Figure 2.6. Zone 2 with floodplain development.

Figure 2.7. A profile of Quaternary floodplain sediments in Zone 2, with post European settlement alluvium probably forming the upper half.

In the upper section of the zone, the modified riparian vegetation continues to be characterized by gorse and willow invasions into the remnant native vegetation similar to Zone 1. The lower parts of the zone vary between open willow riparian woodlands or grasslands, willow swamps, and open shrubby grasslands with cumbungi within the channel or flood channels (refer to Ecosynthesis 1999 for further riparian habitat detail).

Zone 3 Multi-channel clay alluvial floodplains with minor valley constrictions

Zone 3 begins adjacent to Stockdale, approximately 7.8 km below the dam wall and extends approximately 7.6 km downstream. This zone is characterized by broad Quaternary alluvial floodplains, which narrow toward a topographical constriction where the valley walls of sandstone and basalt bedrock form a pinch at the base of this zone. The presence and location of these extensive floodplains suggests a depositional zone of fine sediments resulting from a decrease in river gradient and an increased backwater effect caused by the pinch. This is supported by field observations of a higher clay content in the floodplain material, and a smaller, more sinuous channel than in Zone 2.

The hydrology of this zone continues to be dominated by the releases from the Craigbourne Dam, as the small ephemeral tributaries entering the system are unlikely to have any significant impact. The exposure of the water table in places within back channels, suggests significant potential for groundwater flow into the trunk river.

The floodplain sediments continue to exhibit a topsoil that is probably post European settlement alluvium, which overlies a layer of fine sandy clay. The sediments grade from a sandy clay composition (Roslyn soils of fine texture – Holz 1987) in the upper part of the zone to a finer more clayey type at the lower end (Churchill soil of cracking clay – Holz 1987). There is a repeated sequence of large pools (broadwaters) with low channel banks, which are present above small nick points or where there is flow convergence from multiple channels.

Multiple channel avulsions have taken place throughout this zone, some naturally and others by artificial channelisation. Evidence for this exists where some highly sinuous and shallow channels that have been completely abandoned are present, and in other locations where two channels now appear to be maintained. In some cases, the original channel continues to convey the base flow, and the new channel exhibits headcuts. If these headcuts were to move up the entire length of the new channel, then it would capture the base flow from the original channel. In other situations, the new channel carries the base flow, while the original channel is choked with willows and may well be cumulatively silting up each flood. Headcuts are also evident in the main channel upstream of some avulsion locations, and have probably resulted from the avulsion process. Generally, willow roots, fords, or hard A and B clay horizons of an old soil profile hold many of the headcuts and nick points throughout the zone. In some cases, the willow may have contributed to the formation of headcuts, but this study was insufficiently detailed for this to be confirmed.

Similar to Zone 2, modern benches and small islands have formed within the broader channel and have been colonized by vegetation including willow, grasses and macrophytes. Willows infested the channel throughout this section in the past, but the majority were excavated in 1992 and 1994. Minimal revegetation was conducted and there has been little regeneration of native vegetation. Some of the willow was removed and sprayed between Rosedale and Colebrookdale in 1999 and 2000, again with little revegetation. Willow removal and spraying was conducted in other areas throughout the zone in 2000, with the root balls and stumps having been generally left in place to maintain the benches (Read and Harding, pers. com., and Ecosynthesis 1999).

Now that the willows have been removed with little or no native revegetation or regeneration, the clayey channel banks may be more prone to bank slumping, particularly in response to drawdown (fluctuating flow levels) or grazing access. Although the willow root balls have generally been left in place, there is still also potential for bed and bank scour and/or the reactivation of headcuts to occur in higher flows.

The floodplains have been cleared for pasture and some cropping, with only the odd remnant riparian Blackwood tree, some native grasses and patches of dryland open native forest adjacent to the riparian zone. In sections of the river, willows that have escaped removal are present, and cumbungi is prevalent (refer to Ecosynthesis 1999 for more detailed information). There are particularly dense stands of both at the downstream end of this zone where they constrict the channel and contribute to overbank flow through a swampy area just above the pinch. The floodplains in this section show evidence of past stripping, which is supported by anecdotal information that wheat crops sown on these floodplains had been washed away in past floods. This continues to be a potential risk as well as channel bank toe scour where instream willow and cumbungi deflect the flow onto susceptible (not vegetated) bank toes. If the willow, in particular, were to be removed from these sections, there would be potential for bed degradation and scour of susceptible banks, particularly in higher flows.

Figure 2.8. Zone 3 with broad floodplain development and vegetated benches within the channel

Figure 2.9. Zone 3 indicating the infestation of cumbungi within the channel.

Figure 2.10. Zone 3 where a series of small headcuts and benches are controlled by willow rootballs.

Zone 4 – Tertiary floodplains

Below the basalt constriction at the top of Red Night, this zone opens out into a wide valley of Tertiary and Quaternary floodplains and terraces. It extends for approximately 1.4 km downstream to Brown Mountain Road. The river channel is much wider and straighter than in Zone 3 and has deeply incised erodible Tertiary sediments forming relatively steep banks. A riffle and pool sequence extends throughout this zone, with riffles composed of willow roots or cobble and bedrock. A clayey substrate is also present in some sections. The hydrology of this zone continues to be influenced by the regulated flows released from the dam.

A highly sinuous channel has been cut-off and abandoned by the present channel in the upper part of this zone. At the downstream re-entry point of this meander cutoff a significant change in the bank height from 4-6m to 2.5m occurs. It is likely that a headcut, resulting from the meander cut-off process, traveled upstream and deeply incised the erodible Tertiary sediments forming the present day channel. This headcut is still apparent below the bedrock constriction separating zone 3 and 4. It appears to have been slowed by a change from the erodible Tertiary sediments into harder alluvial clays, the presence of willows, or it may be just where it has reached to at this present time. The willows in the swampy area upstream of the constriction, some of which are acting as a grade control through the constriction, are in effect, only allowing the river to 'trickle' through, and are thereby alleviating the pressure on the headcut. Great care would be required if this willow were to be removed (see Ecosynthesis 1999 for more riparian habitat detail).

Willow removal took place in 2000 extending downstream from where the first cut-off channel begins, to the base of this zone. A few remnant Blackwood trees are now present and some bare and grassed banks with pasture and crops on the floodplains. Macrophytes also occur within parts of the channel. No apparent re-vegetation has been conducted. Minor benches with remaining willow root balls are present within the broader channel and are indicative of vegetation encroachment and channel contraction.

The limited riparian vegetation left to stabilize the channel banks suggests there is potential for the channel bank toe to be scoured in high flows and may contribute to bank slumping where the banks are high. This would be exacerbated by the huge size of the channel, which means it contains a very large portion of flood water, concentrating the energy of the flow rather than dissipating it over floodplains. The channel bed may also now be at greater risk of scour during higher flows, although, the bedrock exposures in the substrate suggest bed degradation may be limited.

Zone 5 - Quaternary floodplains and terraces

Zone 5 is starts approximately 16 km below the Craigbourne Dam. It is a short section characterized by a smaller and shallower channel than Zone 4 flanked by Quaternary floodplains of clayey (Churchill soil – Holz 1987) and sandy clay alluvial and aeolian material (Apricot, Stockdale, Bridge and Inverquharity soils). The river exhibits a clayey substrate with some cobble and bedrock riffles. The hydrology is the same as Zone 4.

This zone is similar to the bottom section of Zone 3, where there is a topographical constriction at the base holding up the floodplains. As such, there is also a greater potential for bank overflow during high flows and therefore potential for increased bank toe and floodplain scour. Willows that once infested the channel throughout this zone were removed in 2000. Some willow rootballs remain within benches that occur intermittently along the channel sides, which are indicative of vegetation encroachment and channel contraction. The remaining vegetation is similar to Zone 4 and there has been no apparent re-vegetation. The removal of willow from this zone, has reduced the within-channel and bank roughness, which may decrease the pressure of overbank flows on the floodplains and therefore lower the risk of stripping. However, the increased flow energy within the channel could result in the bed and banks being more prone to scour during high flows.

Figure 2.11. Zone 5 near the base where channel shallows. Willow debris piles remain from past removal.

Zone 6 - Basalt/Dolerite gorge

The valley constricts to a bedrock gorge below Cranston, 17.7 km below the dam wall and extends for 1.6 km. The gorge is a significant nick point on the river and holds up the floodplains and terraces of zone 4, and to some degree the floodplains of zones 3 and 2 as well. Two gravel pits flank the river at the top of this zone and their tailings contribute to the channel constriction. The hydrology of the river is similar to Zone 5 as there are no significant tributaries that enter the trunk system.

Basalt and dolerite bedrock flank the sides of the steeply incised valley, which has minor floodplains and benches. The channel holds a riffle pool sequence over a substrate of bedrock and an old hard clayey A horizon, which develops into rocky cascades through a cliff-based gorge. The channel banks are alternately composed of bedrock or a clayey loam topsoil layer over old hard clayey A and B horizons, which support the banks. A generally native riparian forest consisting of predominantly blackwood and silverwattle with some mature willows and eucalypts exists. There are layers of largely intact understorey and groundcover with some hawthorn (Ecosynthesis 1999). Willow removal is currently underway (2002). The zone is largely stable, with a greater sediment transport capacity (similar to Zone 1) than in Zones 2, 3 and 4.

Zone 7 – Quaternary alluvial floodplains and minor Basalt constrictions

Below Zone 6, a sequence of Quaternary alluvial floodplains and terraces (with some aeolian deposits) begin near Penrise and extend 11.4 km to just below the confluence of the Inverquharity Rivulet with the Coal River. The floodplains vary in width according to the topography and as the channel alternately lies against the valley walls. Broader floodplains and terraces occur at the confluence of the White Kangaroo Rivulet with the Coal River, Rankins Marsh and Inverquharity. The two narrower sections are constricted by basalt terraces, which begin at Campania House and Churchill.

Similar to Zone 3, the presence and location of these floodplains suggest a depositional zone of fine sediments resulting from a low channel gradient and a sequence of constrictions causing backwater effects, which culminate with a significant constriction at the base of the zone (forming Zone 8). Field evidence again supports this, with the floodplain and terrace material grading from coarse sandy clays (Stockdale and Penrise soils – Holz 1987) to a finer clays (Roslyn and Churchill soils) moving downstream in this zone.

The White Kangaroo Rivulet enters the Coal River near the top of this zone and Native Hut Rivulet joins in the middle at Rankins Marsh. The rivulets are ephemeral, but their catchment areas of 96 km^2 and 44 km^2, respectively, are great enough to provide significant flow contributions to the trunk system during wetter periods. The water table is exposed in some of the flood channels, which may indicate groundwater recharge is also influencing the hydrology of the trunk system. This zone is therefore considered to be hydrologically different from the upstream zones.

A pool and riffle sequence, with intermittent broad waters, occurs throughout the zone. The substrate appears to vary between hard Tertiary clays, cobble or willow riffles, and intermittent bedrock intrusions. The development of benches colonized by vegetation (willow and cumbungi) within the broader channel are similar to that observed in Zones 2 and 3, but with a bigger channel present in this zone. Localized bank scour was observed, usually in association with vegetation and benches, which serve to deflect flow onto susceptible banks. Willow infestations within the channel were apparent, increasing the in-channel roughness, which can resulting in greater potential for overbank flow during higher flows and hence possible channel bank toe and floodplain scour. This may be a greater risk where the channel is confined by valley walls. Localised bank slumping was also evident where banks had been cleared of vegetation and there was stock access.

Avulsion channels are present, which have formed naturally and artificially, and resulted in similar responses to those observed in Zone 3, including altered flow paths, often related to willow infestation of original channels, and headcuts. Two sections of headcuts are particularly worth noting, because of their potential susceptibility to erosion during higher flows. Above the confluence of White Kangaroo Rivulet with the Coal River, it appears that Tertiary clays and willows are holding up a headcut that would be particularly at risk of erosion if the willows were to be removed without care and revegetation. At Riversdale the largest broadwater along the Coal River (within the study area) is located behind a temporary sandbag weir (where sandbags are intermittently removed to release water). Near the base of the broadwater, a very large headcut in layers of sandy and clay alluvium is present at the top of a large and deep avulsion channel, which has been artificially armoured and partially re-vegetated to stop it from reaching the broadwater. This is unlikely to be effective erosion protection during high floods. The main channel immediately below the broadwater has been recently (2002) cleared of willows and dredged, with the more clayey banks battered but not revegetated as yet, leaving them prone to scour. A small degrading headcut is apparent in the unconsolidated clayey sediments that may escalate in time and/or with higher flows. A sequence of small headcuts and nick points consisting of either cobble and pebble riffle or a hard clay substrate occur downstream, which may also be prone to scour in higher flows.

At Inverquharity, in the base of this zone, the channel has incised the floodplains more deeply and has exposed a layer of old river cobble and pebble bed in the Quaternary alluvial material. In parts of this section the clayey banks are steep, and subject to slumping through the lack of vegetation and grazing, while in others a closed gorse shrubland has stabilized the banks, but which may also be susceptible to scour and slumping if the gorse is removed without sufficient re-vegetation.

Some tributary incision was evident, particularly where the White Kangaroo and Native Hut Rivulets entered the trunk channel.

Willow is the predominant riparian vegetation, alternating between riparian woodland to a swamp within the channel. Gorse is also prevalent in some sections and macrophytes (cumbungi) have significantly invaded the channel in areas. Patches of native vegetation (eg. blackwood, eucalypt and wattle overstorey, with native grasses) are present, particularly on the steeper valley slopes, while the floodplains have been largely cleared for pasture and cropping. Some blackwood trees maintain channel banks narrowing the channel in places. A report by Ecosynthesis (1999) provides more detail on the riparian habitat.

Willow removal took place within the upper and middle sections of this zone in 1999, from some parts of the lower sections of the Inverquharity floodplains in 1992-1993, and the remaining parts in 1999-2002, which is on-going. Few areas have undergone subsequent riparian re-vegetation throughout the zone. There is evidence of bank slumping probably as a result of the more recent willow removal. The willow root balls and stumps have generally been left to hold the benches (although not in all cases), which may well also now be subject to bed scour in higher flows and particularly when they have disintegrated after 3-5 years.

Zone 8 – Basalt constriction and Quaternary floodplains

Zone 8 commences below the confluence of the Inverquharity Rivulet with the Coal at Circus House (30.7 km from the dam wall). The channel is entrenched between basalt terraces and steep cliffs. It cascades down a basalt bedrock, boulder and cobble substrate to Nugent Farm at the base of this zone. The bedrock control on the channel and the channel gradient through this constriction are both greater than that observed in the constrictions of Zone 7, suggesting this zone would be more stable and greater sediment transport capacity.

Figure 2.12. Zone 7 with the bigger channel and broad floodplains. Vegetated benches and islands are noticeable within the channel.

Figure 2.13. Zone 7 channel in the upper constriction, with a cobble riffle and bedrock valley wall providing a greater stabilizing influence on the channel.

Figure 2.14. Zone 7 where an abandoned channel is evident within the floodplain.

However, until recently a willow swamp (with a native understorey) choked the channel trapping sediment throughout the zone. Removal of much of the willow in 2002 has exposed a multi-channeled valley floor with numerous benches, islands and minor floodplains of unconsolidated sandy clay overlying a harder clay material. The disturbed alluvial sediments are partially stabilized by remaining willow roots and some native vegetation, but they are prone to scour until they have been re-vegetated.

The hydrology within this zone is still likely to be influenced by the regulated flow release from the Craigbourne Dam, but during periods when the major tributaries entering the trunk system in Zone 7 flow, this zone will exhibit a different hydrology.

Zone 9 – Quaternary and Tertiary alluvial floodplains and terraces

The valley widens below the basalt valley constriction of Zone 8 approximately 32.5 km from the Dam. Quaternary alluvial floodplains are more developed with wider terraces of Tertiary sediments and Quaternary alluvial and aeolian sediments (Roslyn, Churchill, Penrise soil – Holz 1987). The basalt capped terrace continues to border the valley. Where the channel contacts the terrace it exposes scarps of the basalt overlying

Tertiary sediments, which can be seen at St John's Church cemetery in Richmond and approximately 1.3 km upstream of the Richmond Bridge. No significant tributaries contribute to the trunk system, indicating the hydrology of this zone is similar to the above Zones 7 and 8.

The channel exhibits a shallow pool and cobble riffle sequence with a deeper pool behind a small weir in the lower section. An old river bed consisting of weakly cemented cobbles and boulders in a finer matrix, possibly of alluvial and colluvial origins, is exposed within parts of the present river bed and banks. This material may be influencing the bed and banks in places, but has been eroded through in others to underlying Tertiary clays. The presence of the larger material in the old river bed indicates a time when the river flow regime was much greater.

The channel is generally shallower and narrower, with a consistently coarser bedload more than in Zone 7. However, the channel still exhibits intermittent modern benches and islands of vegetation that are indicative of vegetation encroachment and channel contraction. Abandoned channels are also present on the floodplains and Quaternary alluvial terraces.

The riparian vegetation consists largely of a gorse, boxthorn and grass understorey, and some willow with a few native species of wattle and blackgum (see Ecosynthesis 1999 for more detail). No woody debris was obvious within this zone. Some willow excavation from the channel has been conducted in the recent past through this section.

Zone 10 – Basalt gorge and weir pools

At the top of this zone, the basalt capped terraces narrow to form a gorge at Richmond, which starts 33.4 km from the dam wall. The channel is flanked by narrow benches and steep sided walls (not rocky) vegetated with riparian willows. Active narrowing of the gorge is occurring with urban settlement, particularly where imported spoil has been added to the slopes in places. The character of the channel is dominated by weir pools and associated fine sediment deposits that have accumulated behind two major weirs below Richmond Bridge.

Below the gorge, the channel has incised through Quaternary floodplains and terraces that are bordered by more extensive and higher terraces of Tertiary sediments. Bedrock controls the bed leading up to the second weir, but again fine sediment is deposited in the backwater of the second weir. The weir occurs at the base of a sandstone cliff, which confines and deflects the river. This second weir marks the downstream boundary of the study area as the channel becomes estuarine below this weir.

The effects of the regulated flows from the Craigbourne Dam are probably dampened in this zone due to the distance from the Dam, the extra flow contributions from tributaries (particularly during wetter periods) between this zone and the Dam, the large amount of water abstraction from the trunk system, and the fact that 90% of the zone is weir pool. Flow velocities are also generally lower due to the low channel gradient and the weirs. It is thus considered that the localised effects of the gorge, urban development, channel abstraction, vegetation, landuse and the weir pools would over ride any influence of Craigbourne Dam on the channel geomorphology. The hydrology would also be less influenced by the regulated flows of the Craigbourne Dam, except in dryer periods when tributaries contribute no or little flow to the trunk system.

Summary of Important Factors Related to Zones

A summary of the major characteristics and relative susceptibility to change is identified for each zone in Table 2.1.

Table 2.1. Major characteristics of geomorphic zones and their inherent susceptibility to change relative to each other.

Zone	Major Characteristics	Inherent Susceptibility to Change (risk)
1	Bedrock controlled (dolerite)	**Low**
2	Partially confined valley (dolerite and sandstone) with some bedrock bed and bank control, and cobble riffles. Incised channel with benches, and sandy clay alluvial banks, floodplains and Quaternary alluvial terraces.	**Low** where bedrock controlled **Moderate** where localised bank scour present in alluvial sections
3	Predominantly alluvial clay benches and banks with incised channel in broad floodplains and Quaternary alluvial terraces. Multiple channels.	**Moderate - High**
4	Tertiary sandy clay sediment banks, with deeply incised channel in broad Quaternary and Tertiary floodplains and terraces. Some cobble and bedrock riffles.	**High** where headcuts and bank scour occur **Moderate** where bed is controlled by bedrock, but localized scour of alluvial banks is present
5	Quaternary alluvial clay banks, floodplains and terraces. Some cobble and bedrock riffles.	**Moderate** where bed is controlled by bedrock, but localized scour of alluvial banks is present
6	Bedrock controlled (dolerite and basalt)	**Low**
7	Partially confined valley (basalt terraces) with minor bedrock bed and bank control and some cobble riffles; alternating with a channel incised into alluvial units of sandy clay and clay with some cobble and pebble riffles, many benches, and broad floodplains and Quaternary terraces. Includes the White Kangaroo and Native Hut confluences.	**Moderate** where bed is controlled by bedrock, but localized scour of alluvial banks is present **High** where headcuts and bank scour present
8	Bedrock controlled (basalt)	**Low**
9	Incised channel with alluvial benches, floodplains and Quaternary or Tertiary terraces flanked by basalt sheet terrace. Alluvial and Tertiary clay bed with cobble riffles.	**Moderate**
10	Bedrock controlled (basalt and sandstone) alternating with Quaternary alluvial banks, floodplains and terraces and Tertiary terraces. Cobble riffles and fine sediment deposits. Includes two major weirs.	**Low** Bedrock controlled bed and slower flow velocities with low channel gradient and weir pools

2.2 Effects of flow regulation on the lower Coal River System

This section predominantly focuses upon the physical changes that could be expected with further modification to the flow regime of the Lower Coal River system. Existing baseline data is limited for the lower Coal River, but there are known impacts of dam regulation and abstraction to fluvial geomorphology. A review by Telfer in Davies et al (2002) outlines these, which is briefly summarized below.

A dam has direct effects on the transfer of water and sediment within a river system. These first order impacts in turn cause a change in the river morphology. In response to both these first and second order impacts, the ecology of the system is also altered. The likely effects of these are then discussed with respect to the lower Coal River. Not all the potential impacts could be examined thoroughly due to time constraints.

2.2.1 First order impacts – flow and sediment

The flow regime of the lower Coal has been considerably modified by regulation. The present flow is now characterized by higher base flows, reduced periods of very low or no flow, truncated flood flows, a lower frequency of high flood flows, and a shift away from the annual winter floods and a smoothing of seasonal cycles (Figures 1.1-1.4).

In the period between 1988 and 2001, high flood flows at Craigbourne Dam have been reduced from >50 cumec to <30 cumec, and median flood flows have dropped from 12.7 to 1.7 cumec (based on DPIWE mean daily flow data, Figure 1.3). Based on a peak flood correlation analysis between Craigbourne and Richmond (Davies unpub. data) and the post-dam change in median flood flows at Craigbourne, the natural median flood flows at Richmond appear to have dropped from 26 cumec to a post-dam level of around 3.5 cumec (see also Hydro 1995). Using the rating curve of the Creeses weir gauging station upstream of Richmond Bridge, a median flood flow of 3.5 cumec would result in a flood level at approximately 0.6 m gauge height. The current height of the broad channel bank (not including within-channel benches) at this location is approximately 1.0 m, which approximates the Richmond pre-dam median flood flow of 26 cumec.

Comparison of modeled natural flows at Craigbourne Dam with the post dam historical flows also indicates that the frequency of high flood flows (>30 cumec) has dropped from 5 in 13 years to 0, between 1988 and 2001. In this same period, the proportion of mean daily flow less than 0.01 cumec that occurred naturally has been reduced from 29.3% to 8.3% at Craigbourne Dam and from 27% to 2.2% at Richmond, post dam construction. Limited data was available for an assessment of the intra-daily variation in flows, and so an investigation of these was not conducted within this study. The potential for drawdown induced bank failure was therefore not assessed.

In all probability, the Craigbourne Dam has also altered the sediment balance of the lower Coal River system. In a review by Telfer in Davies et al (2002), sediment trap efficiencies for large dams within Australia were noted to exceed 95%, and although the sediment trap efficiency for the Craigbourne Dam has not been calculated, it is likely to be similar. As a result, the majority of the bedload is trapped behind the dam and only the finer suspended sediments have the potential to be transported through or over the dam in high flow events. The major downstream sources of sediment now come from tributaries and where the trunk channel bed, banks and floodplains are being reworked.

The lack of sediment passing through the dam can result in sediment starvation below the dam. This refers to the situation where flows have the capacity to transport more sediment than they are carrying when they are released from the dam. As a result, those flows have the potential to erode any available sediment.

The development and behaviour of a river form reflect the flow regime and sediment load, so if any alterations to these occur, then you could expect changes in the river morphology.

2.2.2 Second Order Impacts – River Morphology

The regulation of river flows can lead to many varied responses in the river morphology. Telfer, in Davies et al (2002), provides a good explanation of the different effects that may be expected from a regulated flow regime, including bed degradation and aggradation, channel contraction and expansion, river planform changes, tributary rejuvenation, bed armouring and siltation.

Telfer suggests that bed degradation can be common where sediment is trapped behind the dam causing sediment starvation in the system downstream, and when the flows are sufficient to entrain bed material.

Channel widening can occur by mass failure (slumping), which can be driven by waterlogging of banks, scour of bank toe, or bed incision. All three processes can be exacerbated or driven by river regulation.

Pool infilling and tributary mouth bars may result when sediment is available in response to truncated flood flows, less frequent high flood flows and if the regulated flows are no longer competent enough to entrain bed material.

Channel contraction may also result when the dominant discharge or 1-2 year flood, which is generally considered responsible for the shaping of the channel form in alluvial systems, is reduced by regulation and there is a sediment source for deposition. Examples of channel contraction include the development of discontinuous benches and side bars along the channel, which may often be colonized by vegetation (trees, shrubs and macrophytes).

These processes and those mentioned above, may also influence the river planform.

Tributaries may be subject to incision where bed degradation and widening occur, but also if the discharge peaks in the tributary and trunk system are not in sync.

The effects of dam regulation can reduce the level of floods that are competent enough to mobilize the coarsest bed sediments, and increase moderate flows that are only able to flush fine sediments from the bed surface. Over an extended period this flow regime may coarsen and armour the bed surface so that it less able to be mobilised. Consequently, there is potential for fine sediments to infiltrate the layers underlying the stable coarse substrate, causing siltation.

2.2.3 Third Order Impacts – Ecological Implications

Alterations in the flow regime and sediment balance due to regulation, can adversely affect the ecology within a river system and it's estuary, with particular reference to the impacts on water quality and habitat. Telfer in Davies et al (2002) reviews these potential impacts, which include the sedimentation of interstices in river bed substrates, vegetation invasion, floodplain wetland disconnection from the river, and changes to the natural wet/drying cycle of wetlands.

2.2.4 Summary of potential impacts relevant to the Lower Coal River

- Channel instability — in particular bed degradation and bank erosion (because of the reduced sediment load from the high sediment trapping efficiency of the Craigbourne storage), and channel contraction (due to reduced channel forming flows).
- Bed mobility — potential for amouring due to moderated flows.
- Siltation — potential for changes in sediment characteristics with regulated flows.
- Tributary rejuvenation — potential occurrence in relation to bed degradation or desynchronisation between tributary and trunk systems
- Vegetation responses — encroachment potentially altering river morphology with modified flows.

An assessment of the ecological impacts was not pursued in this geomorphological study, but is discussed in a subsequent chapter.

2.3 Preliminary Assessment of Effects of Regulation on morphology

The potential effects of regulation on the lower Coal River were highlighted in the above section and are now discussed with respect to the identified geomorphic zones.

2.3.1 Channel Instability

Aerial photographs of the lower Coal River were examined, which covered runs in 1946 (earliest available) and 1984 shortly before dam construction and 2001 (most recent and post dam). Between 1984 and 2001, there was some indication of bed degradation, and channel contraction was significant and widespread. A minor degree of channel contraction was also apparent between 1946 and 1984. Time constraints prevented a detailed study and quantification of the amount of bed degradation, channel contraction and any changes in the location of riffles and bars.

Bed Degradation

Bed degradation was noted in the top of Zone 2 where a lobe of coarse sediment present within the channel in 1984 appeared to have been incised by 2001. Field observations support this and it is considered that Zone 1 and the top of Zone 2 are subject to sediment starvation resulting from regulation. Bed degradation was not so obvious in Zone 1, because of the bedrock controls on the river bed.

Further evidence of localized bed degradation included incision of meander cut-offs in Zone 3 and an obvious upstream shift of a major headcut in Zone 7 between 1984 and 2001. Several headcuts of varying degrees and some scour in pools in the alluvial zones of this system were also observed during field work (particularly in Zone 4, but also in 2, 3, 7, and 8), but they were not all necessarily active. It is probable that the long history of poor landuse practices (eg. vegetation clearance, unrestricted stock access, channelisation, willow invasion and removal sequences, and weir and ford constructions) along the river have been more influential in the causes of these examples of degradation rather than river regulation. This is supported by the observation of the some of the same examples or similar types of bed degradation (eg. headcuts) occurring throughout the river between 1946 and 1984.

Channel Widening

Localized scour and slumping were observed in the field, particularly within Zones 2, 3, 4 and 7, which indicates there may be some channel widening taking place. The scouring appeared to be related to the presence of vegetation growing on benches or within the channel, deflecting the flow onto susceptible channel banks (often sandy with little vegetation and/or unrestricted stock access). The slumping may have been related to drawdown failures in more clayey banks, bed incision, vegetation clearance (including willow removal) and/or unrestricted stock access.

Channel Contraction

Channel contraction was apparent to varying degrees within each zone along the lower Coal River, as evidenced by the presence of discontinuous benches and side bars along the channel that were colonized by vegetation (particularly willow and cumbungi). In 1984, the channel exhibited extensive sequences of exposed riffles and bars that were much less obvious in 2001 photos and in field observations, because of vegetation encroachment into the channel. The change was particularly evident between the aerial photographs within Zones 1, 2, 4, 8 and 9, and may have also occurred in other zones, but riparian vegetation obscuring parts of the channel in pre-dam photos prevented an assessment. Flood channels present in Zone 3 also appeared to have a greater degree of bank scour in 1984.

Vegetation encroachment into the channel could also be discerned between 1946 and 1984, but the channel was generally still much clearer in 1984 than in the present. Landuse practices and river management since European settlement have probably contributed to the general channel incision and contraction. The river appears to be presently recovering from past channel incision, dredging and straightening. It is suggested that the river may be between the stages of degradation and widening, and aggradation and widening that are recognized as separate stages in the recovery process of incised streams (Simon and Hupp 1990). Alternate channel bars, incipient meandering of the channel and localized channel widening are evident in many zones, and are considered to be common features of the aggrading stage of recovery.

However, it appears that the reduction in higher flows that maintain the channel form and an increase in low flows with river regulation, in combination with sediment availability below the dam from tributaries and reworked bed and banks, are significantly driving and/or compounding the present day channel contraction. The presence of the invasive species of willow and cumbungi also enhance these effects.

River Planform

The numerous avulsion channels and abandoned meander channels apparent in the alluvial Zones 2, 3, 4, 7 and 9 indicate that the channel planform has been significantly different in the past. Some of these alterations have occurred since 1946, with the development of a few channel cut-offs, and the swapping of the main river flow to pre-existing avulsion channels (Zone 3). Minimal changes were apparent between the pre-dam 1984 photos and the present. A present-day flood channel in the top half of Zone 3 appeared to be more scoured and free of vegetation in 1984 than in the present, suggesting it may have carried flows more often before the dam. Several channels cutting-off meanders in the middle of Zone 3 appear to be more scoured with less vegetation in the present compared to their form observed in 1984 photos. Anecdotal evidence (Harding pers. com) suggests these particular meander cut-off channels have been artificially created. The majority of changes to the plan form appear to have occurred in either early European settlement or well before, during the Quaternary period. Avulsions that have occurred since European settlement may well have been in response to the infestation of willows into the main channel causing overbank flow and channel diversion during high flows. Alternatively, native vegetation clearance exposing the adjacent floodplain alluvium to erosion during high flows, may have also been responsible, either separately, or in combination with willow infestation of the channel.

2.3.2 Bed mobility

Preliminary fieldwork revealed little evidence for armouring of cobble riffles and bars within any of the zones. In sections of the river that were not controlled by bedrock, some cobble riffles displayed slightly coarser material overlying finer sands and silts, but they were not cemented or imbricated. Sources for large coarse material are generally lacking throughout the lower Coal, compared with the readily available gravel, sand and mud. This limited size fraction availability may prevent the development of armouring, because the regulated flows may well be able to mobilize the finer bed sediments to a certain degree. It was beyond the resources of this project to conduct detailed analyses of the sediment characteristics and the competence of the average moderated or maximum regulated flow that would be necessary to provide a more conclusive assessment of the bed mobility.

2.3.3 Siltation

Craigbourne Dam is probably trapping all coarse sediment, as previously discussed, and allowing only very fine suspended sediments over the spillway and through the dam valve. There are sediment sources below the dam, however, which include tributaries and reworked bed, banks and floodplain sediments. The development of benches and bars occurring intermittently in the channel of each zone, as previously discussed, indicate that a degree of siltation is occurring throughout the Coal River system.

It is not clear, however, as to whether fine sediments are filling the interstices in coarser substrates that are not being mobilised, because armouring was not observed. Limited resources and a lack of baseline data have prevented an assessment of changes in the pre- and post-dam levels of silt in the channel. There is also evidence to suggest that there has been a build up of sediments at the top of Pitt Water estuary (Mitchell pers. com.), but it is not clear from what time period the sediments have been derived.

2.3.4 Tributary Rejuvenation

In Zones 2 and 7, significant tributary incision was observed. Aerial photographs indicate that this incision had already occurred by 1946, and therefore was not related to the construction or operation of the Craigbourne Dam. It is likely that as the main channel incised (possibly in response to poor catchment land practices and river management), the tributary adjusted to the altered base level leading to incision of the tributary channel.

Desynchronisation of the peak discharges down the trunk and tributary channels may have also caused the incision, because the catchment is known for it's localised rainfall events that have the potential to result in greater flows down a tributary compared to the trunk system. This natural potential for desynchronisation of peak channel flows may mean that any further incision in response to post-dam desynchronisation of flows, due to regulation, is unlikely. Further investigation would be required to confirm this assessment.

2.3.5 Vegetation responses

Catchment and riparian vegetation can have a significant influence on the geomorphology of a river system and when disturbed, can cause profound changes to the system. Prior to vegetation clearance, floodplain and adjacent riparian vegetation would have been composed of forest, woodland and swamp species like *Eucalyptus ovata* (swamp gum), *E. viminalis* (white gum), *Acacia melanoxylon* (blackwood), *Acacia dealbata* (silver wattle)*, Pomaderris apetala* (Dogwood)*, Leptospermum lanigerum* (woolly tea tree)*, Allocasuarina verticillata* (she-oak) and various macrophytes (Askey-Doran 1993, Ecosynthesis 1999). Introduced exotics have now replaced and/or invaded the majority of the riparian vegetation in the Lower Coal River system. Crack willow, gorse, boxthorn, hawthorn, briar, cumbungi and introduced pasture grasses dominate the list of exotics found (Ecosynthesis 1999).

Willows are particularly adept at colonizing disturbed alluvial surfaces, invading channel banks and beds, and contributing to channel contraction and flow diversions within a river. Where willows choke a channel there is also an enhanced possibility of overbank flows causing bank toe and floodplain scour. There is evidence for each of these effects throughout the Lower Coal River system where the growth of willows has been prevalent in sections since well before 1946 (see above discussion for channel contraction). At the base of Zones 2 and 3, within sections of Zone 7, and throughout Zones 8 and 9, the invasion of willows into the channel appears to have significantly contributed to reduced channel capacity, flow diversions (multi-channeling and avulsions) and over-bank flow across floodplains.

The increase in low to moderate flows with less seasonal variability and the reduced high flows in the lower Coal River due to regulation, have also provided ideal conditions for vigorous willow growth.

Anecdotal evidence suggests willow removal from sections of the river has been carried out at various times over the last 40 or so years (at least), but was very limited in its long-term success. A more intensive and systematic program of willow removal is currently being conducted through the local Landcare Group, with plans for revegetation of sites where willows have been removed. Very little revegetation has been conducted to date. Where native vegetation is absent along the lower Coal River, willows do have the positive effect of stabilizing banks and headcuts. Willow removal can disturb sediments and anecdotal and field evidence suggests that the regulated flows have been sufficient to flush some finer silts and cause minor bank scour at removal sites.

The prolific growth of gorse has had similar impacts on sections of the Lower Coal River, but it is restricted more to channel banks and some benches.

The historical levels of large woody debris in the Lower Coal River are not known. The observed type of remnant native vegetation and the noticeable absence of large woody debris in field observations suggests, however, that levels have probably been significantly reduced with native vegetation clearance and replacement by willow, and the trapping of any debris from the upper catchment in Craigbourne Dam.

2.3.6 Summary of flow effects

In summary, the affect of flow regulation from Craigbourne Dam and associated irrigation management on river geomorphology has been to:

- Significantly enhance contraction of the channel, associated with sediment infilling from local or tributary sources and vegetation invasion;
- Reduce the overall competence of the river to transport sediment.

These effects are related to changes in the high/flood flow regime. Other impacts on sediment dynamics also occur due to the storage of previously mobile coarse sediments in the Craigbourne Dam storage. However, without a detailed assessment of sediment transport, distribution and fate (eg. both within the river channel and in the estuary), the significance of this issue remains unknown.

A major consequence of flow regulation is the increased risk of major channel adjustment/damage from large floods as a consequence of the accumulation of material in-channel in the absence of regular annual or mid-sized flood events.

3. ENVIRONMENTAL CONDITION – RIVER BIOTA

3.1 Background

This section describes the condition of the instream biota in the Coal River from existing published and unpublished sources. Limited data on stream fish and macroinvertebrates were made available from recent DPIWE surveys conducted for the National River Health Program, State of the Rivers reporting and specifically for this study, as well as from surveys conducted by the Inland Fisheries Service.

Bennison (1975) and Sloane (1976) both described aspects of the biota of the Coal River from snapshot surveys conducted in 1975 and 1976. Little further work has been done since then, with four sites electrofished in the 1980's and early 1990's by the then Inland Fisheries Commission. Recent macroinvertebrate sampling has been limited to rapid assessment live-pick sampling at four sites in the Coal downstream of Craigbourne Dam in 1998/99. Data on macrophytes are limited, and information on riparian vegetation has been recorded by Ecosynthesis (1999).

3.2 Fish and Fisheries

Sloane (1976) and Bennison (1975) both reported on the fish communities within the upper and lower Coal prior to Craigbourne Dam. All sites were dominated by exotic species – mainly brown trout, with redfin perch and tench also recorded. The shortfin eel (*Anguilla australis*) was abundant, but few other native fish were reported.

Subsequent surveys of four of Sloane's original sites in the 1980's, early 1990's and again in 2002 have shown a marked decrease in abundance of both exotic and native fish, as well as in overall fish diversity (Table 3.1, Figure 3.1). The significant decrease ($r = 0.95$, $p < 0.001$) in abundance of shortfin eel (*A. australis*) is likely to be due to the increase in instream barriers, while decreases in abundance of brown trout ($r = 0.91$, $p < 0.01$) may be attributed to several causes – reduced winter flows (for spawning and rearing), instream barriers and sedimentation of spawning and egg rearing sites.

Another factor influencing the abundance of fish in the Coal is the presence of dense infestations of willows. While these infestations are related to increased in-channel sedimentation and reduced winter flows (see Section 2, and Daley 1999), they lead to reduced productivity and habitat quality for fish (Read 2001). Table 3.1 compares fish abundance data in two reaches of the Coal within which sites were infested with willows or had been cleared of willows. Both density and diversity of fish (native and exotic were higher at cleared than at infested sites.

Table 3.1. Abundances (n/100m) of native and exotic fish at four sites in the Coal River downstream of Craigbourne Dam between 1976 and 2002. Survey data from Sloane (1976), IFS (unpub. data) and DPIWE (unpub. data.).

	Site location :	**Tunnack**				**Baden**				**Pitcairn Hill**				**Rosedale**			
	Site name :	**1**				**2**				**3**				**4**			
	Date :	1976	1985	1993	2002	1976	1985	1993	2002	1976	1985	1993	2002	1976	1985	1993	2002
	Species														**NS**	**NS**	
Natives	*A. australis*	4	1			12	3	3		19	18	13	1	25			2
	P. urvilli									1							
	R. tasmanica																
	G. maculatus											2					3
Exotics	*P. fluviatalis*								1	1	2	1		15			3
	S. trutta	88	36	15		15	5	1		16	8		1	5			
	T. tinca	5	24	5		3	79	5	2	3				1			6
	N all species	**3**	**3**	**2**	**0**	**3**	**3**	**3**	**2**	**5**	**3**	**3**	**2**	**4**			**4**
	N native species	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**2**	**1**	**2**	**1**	**1**			**2**
	Abundance (Native)	**4**	**1**	**0**	**0**	**12**	**3**	**3**	**0**	**20**	**18**	**15**	**1**	**25**			**5**
	Abundance (Exotics)	**93**	**60**	**20**	**0**	**18**	**84**	**6**	**3**	**20**	**10**	**1**	**1**	**21**			**9**

Table 3.2. Abundances (n/100m) of native and exotic fish at two willow infested and cleared sites in the Coal River downstream of Craigbourne Dam in 1976 and 2002. Data from M. Read (PhD thesis 2001, unpub. data).

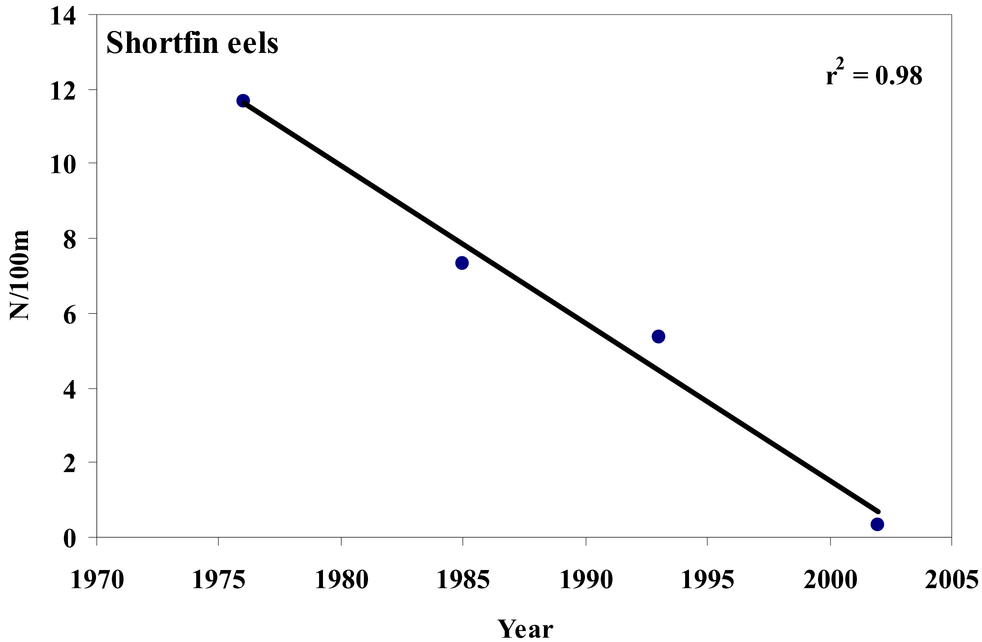
		Coal Stockdale		**Coal/Inverquarity**	
	Species	**Removal**	**Willow**	**Removal**	**Willow**
Natives	*A. australis*	11	3	49	3
	P. urvilli	1		3	
	R. tasmanica			2	
	G. maculatus			1	
Exotics	*P. fluviatalis*	10	2		1
	S. trutta			16	
	T. tinca		1		
	N all species	**3**	**3**	**5**	**2**
	N native species	**2**	**1**	**4**	**1**
	Abundance (Native)	**12**	**3**	**55**	**3**
	Abundance (Exotics)	**10**	**3**	**16**	**1**

The recreational trout fishery in the Coal River has suffered a decline in angler numbers since the mid 1980's (Figure 3.2, IFS unpub questionnaire survey data). As experienced elsewhere in the state, the decline in anglers is highly likely to be a response to the decline in catchable fish, and there is a marked downward trend in mean catch/day. The decline in both measures was statistically significant ($r = 0.45$, $p < 0.05$ and $r = 0.78$, $p < 0.0001$ respectively), and the trend in catch/day was matched by the trend in decreasing numbers of brown trout caught in electrofishing surveys.

In summary, fish abundance and diversity has decreased in the lower Coal River downstream of Craigbourne Dam since the 1970's. This is likely to be due to a combination of factors related directly to the effects of Craigbourne Dam (changes in flows), or indirectly, through enhanced in-channel sedimentation (due to reduced floods) and willow invasion, and construction/development of instream barriers for control and water abstraction.

The condition of the Coal River fish community is poor, with low diversity and abundance of native fish, a relatively high proportion of exotic fish (though with decreased abundance due to poor environmental conditions), and a reduced abundance of recreational species (brown trout). The native fish community is in need of restoration through enhanced fish passage at downstream weirs, willow removal and improved flows.

Abundances of brown trout also fall well below those observed in a number of other south-eastern rivers (Davies 1995, IFS unpub. data). This has been accompanied by a decline in the recreational trout fishery in the Coal both in terms of catch/day and in angler visitation. The Coal now ranks outside the top 20 river fisheries in the state and the top 35 of all trout fisheries statewide. Craigbourne Dam compensates slightly in recreational fishery amenity for this decline, though this fishery has also declined in productivity since the late 1980's mainly due to limited brown trout recruitment and poor water quality.



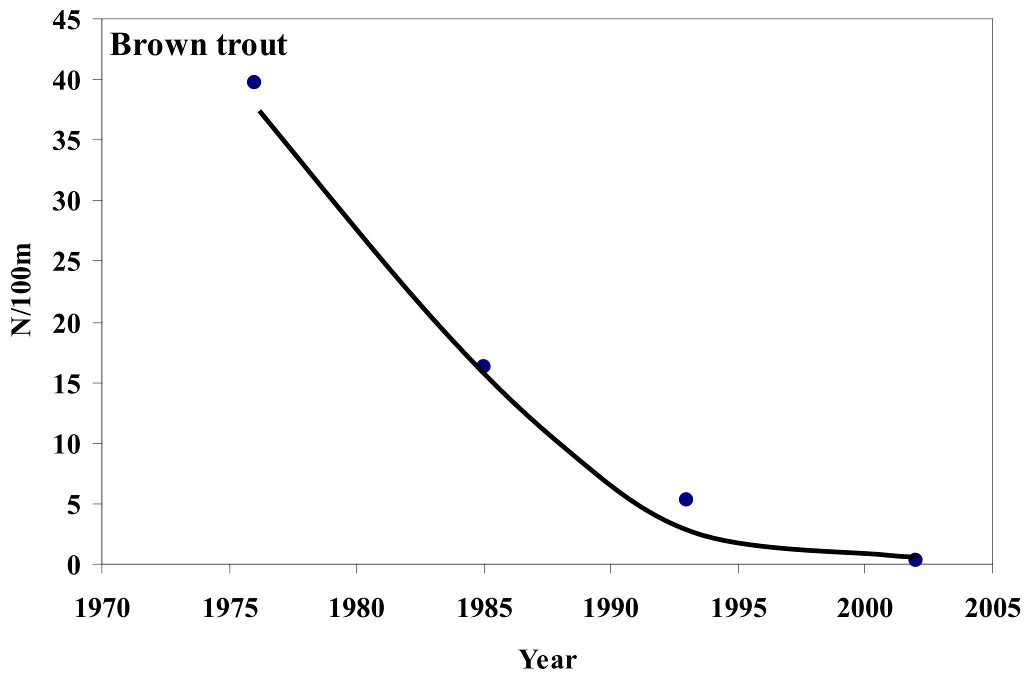
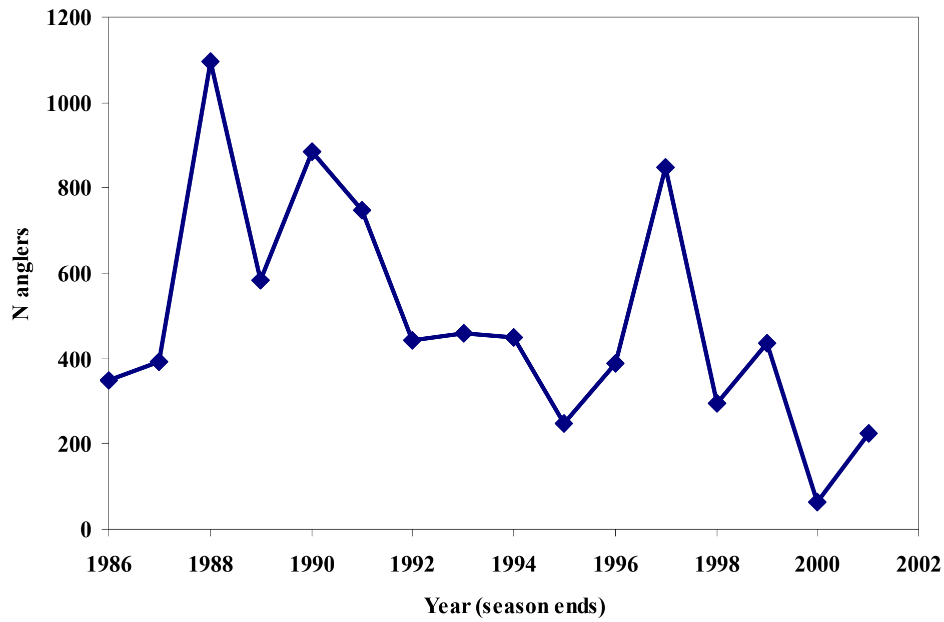


Figure 3.1. Trends in mean abundance of shortfin eels and brown trout at three sites in the lower Coal River since 1975 (see Table 3.1).



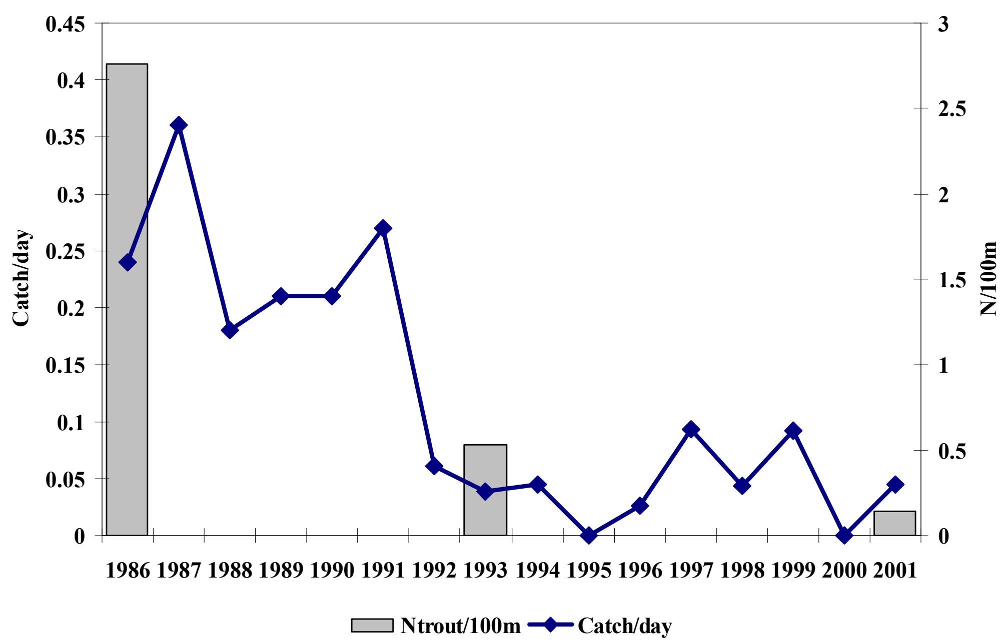


Figure 3.2. Trends in number of anglers fishing in the Coal River (excluding Craigbourne Dam) and their mean brown trout catch/day between 1985/86 and 2000/01. Vertical bars indicate mean N adult brown trout/100m for three sites in the lower Coal.

3.3 Macroinvertebrates

Bennison (1975) and Sloane (1976) both described the macroinvertebrate fauna of the Coal from quantitative and semi-quantitative sampling, respectively. Sites in the lower Coal were generally dominated by bugs (Micronectid Hemiptera), chironomids, damselflies (Zygoptera – *Ischnura*), amphipods (*Austrochiltonia*), shrimp (*Paratya australiensis*), Caenid mayflies, Hydrobiid snails, and Leptocerid caddis. This composition reflects the predominantly pool margin habitat sampling conducted by Bennison, who did not report pool or riffle sample data separately.

Sloane (1976) conducted more systematic separate riffle and pool sampling, reporting percentage compositional results separately for each habitat. At two sites in the lower Coal, riffle habitats were dominated by baetid mayflies, blackflies (*Austrosimulium*), shrimp (*Paratya*), and amphipods (*Austrochiltonia*). Pools were dominated by *Paratya*, Isopods (*Colubotelson*), Leptocerid caddis, damselflies, hemiptera, and Caenid mayflies (*Tasmanocoenis*).

Overall, the pool macroinvertebrate fauna was typical of slow flowing, macrophyte-dominated habitats. The riffle fauna was distinguished by the presence of several faster flow-loving taxa but also contained pool fauna. Thus the macroinvertebrate fauna of the lower Coal in the 1970's was typical of slow flowing, shallow water pool-dominated river systems of south-eastern Australia.

Recent sampling in 1998-99 was conducted by DPIWE for the National River Health Program. Differences in methods and the use of semi-quantitative sampling do not allow an assessment of changes in abundance or diversity since the 1970's. The dominant taxa in the DPIWE kick, live-pick samples were as follows (in order of decreasing relative abundance):

Riffles	Orthocladiinae, Ceinidae, Simuliidae, Hydrobiidae, Conoesucidae, Leptophlebiidae, Hydrobiosidae, Hydropsychidae, Elmidae.
Channel edges	Ceinidae, Leptoceridae, Hydrobiidae, Sphaeriidae, Corixidae, Leptophlebiidae, Hydroptilidae, Veliidae, Orthocladiinae.

These are broadly consistent with the fauna described by both Bennison and Sloane. However, a repeat of the quantitative rifle sampling conducted by Sloane (1976) is required to assess any changes in composition of the macroinvertebrate fauna of the Coal.

Analysis of the 1998/99 riffle habitat kick sample macroinvertebrates data using the Tasmanian AUSRIVAS models allows an assessment of the overall condition of the macroinvertebrate communities relative to a regional reference (least impacted) condition. These data were analysed using the state wide combined season riffle AUSRIVAS models based on presence/absence transformed family level data. A significant increase in O/E ($r = 0.945$, $p = 0.015$) was observed with distance from Craigbourne Dam (Figure 3.3). All sites were significantly to severely impaired, falling into the B or C impairment bands. The O/E score represents the relative loss of taxa compared with what is expected under the reference condition of minimal human impact. Thus, sites between the dam and Pitcairn Hill fell into the severely impacted band, with 41 to 56% of expected macroinvertebrates taxa missing. Sites in the vicinity of the Estate Road Bridge and Daisy Banks were in better condition, though still significantly impaired, with 28% of expected taxa missing.

This suggests that environmental conditions are improving with distance downstream of Craigbourne Dam, probably correlated with an increase in baseflows due to natural catchment inputs and reductions in the severity of flow regulation with distance from the dam. The reach immediately downstream of the dam often experiences cease-to-flow events for several months during winter-spring. The SIGNAL index also increases slightly with distance downstream of the dam, though it is typically conservative in its response (i.e. staying close to 6 to 7 in value). These results do suggest, however, that water quality is not severely impacted enough in the lower reaches to counter the effect of improved conditions due to higher flows.

Overall, these results indicate that the macroinvertebrates communities of the lower Coal are severely impacted by changes in flow/sediment characteristics near the dam. There is some recovery downstream, though all sites show a significant level of disturbance with losses of between 30 to 56% of expected taxa.

No species-level analysis has been conducted on the macroinvertebrate data for the Coal. Species level diversity (highly correlated with family level diversity) is undoubtedly reduced. However, the presence of any threatened species cannot be established.

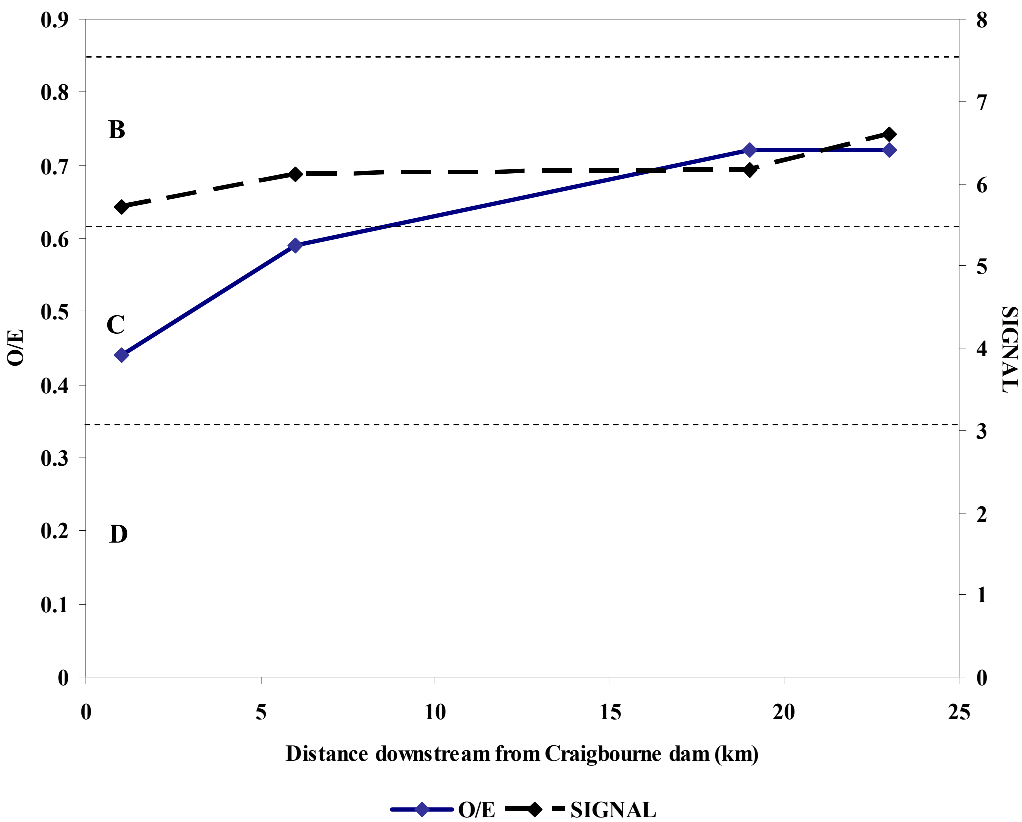


Figure 3.3. Plot of macroinvertebrate O/E and SIGNAL indices against distance from Craigbourne Dam derived from AUSRIVAS kick samples taken in 1998/99 (raw data from DPIWE).

3.4 Macrophytes

There are no comprehensive contemporary data records for aquatic macrophytes in the Coal River. No formally listed threatened/rare freshwater aquatic plant species are recorded in Coal or its catchment (other than *Lepidium pseudotasmanicum*, the shade peppercress, recorded from a small tributary near Richmond). Bennison (1975) and

Sloane (1976) both noted the presence of extensive patches of macrophytes in the lower Coal, mainly associated with pools. Bennison observed the presence of *Rumex bidens*, *Eleocharis sphacelata*, *Myriophyllum elatinoides*, *Phragmites australis*, *Triglochin procera*, *Potamogeton ochreatus*, *Lepilaena preissii*, and *Juncus* sp. in or along margins of pools in the lower Coal. Sloane (1976) observed the same species, as well as the exotic *Elodea canadiensis* (at a site near Pitcairn Hill). Most of these species are still observed, but there are no data to assess their extent, significance or whether they are in decline or not.

Ecosynthesis (1999) noted the presence of *Eleocharis sphacelata Triglochin procera*, and *Elodea canadiensis* as well as *Cyperus lucidus*, *Schoenus fluitans*, *Azolla filiculoides* and *Rorippa nasturtium-aquaticum* in several reaches of the lower Coal.

Askey Doran (1993) observed three aquatic plant communities in the Coal, often adjacent to developed pasture/grazing land. The three types were:

- *Isolepis fluitans* - *Myriophyllum salsugineum* - *Ranunculus amphitrichus* aquatic herbland. Found in water up to a metre in depth, mainly in pools, but also in slow flowing water. The substrate can be either silt or a silt/rock matrix.
- *Triglochin procera* - *Aponogeton distachyus* - *Elodea canadensis* aquatic herbland. Found in water depths up to 0.8 metres, in either slow flowing water or pools, and to a lesser extent fast flowing water. Substrate is either silt or a silt/rock matrix.
- *Potamogeton ochreatus* - *Triglochin procera* - *Callitriche stagnalis* aquatic herbfield. It was found in water depths up to 0.5 metres and predominantly in pools, although may occur in both fast and slow flowing water. Substrate can be either silt or a silt/rock matrix.

None of the macrophyte species observed in the Coal have particular conservation significance in themselves. The presence of aquatic macrophyte habitats is, however of broader ecological significance, as these habitats support a diversity of aquatic algae, invertebrates and may serve as refuge habitats for juvenile fish.

3.5 Riparian vegetation

Askey-Doran (1993) and Johnson (2001) described riparian vegetation assemblages from the Coal River from selected high value remnant vegetation sites. There is no overall assessment of the state of riparian vegetation throughout the lower Coal, but it is generally accepted as being highly degraded (Askey-Doran DPIWE pers. comm.), with only occasional remnants. As previously indicated, a variety of exotic plants including crack willow, gorse, boxthorn, hawthorn, cumbungi and introduced pasture grasses have replaced much of the natural riparian vegetation.

Ecosynthesis (1999) have mapped the distribution of dominant riparian habitats/communities between Craigbourne Dam and Richmond. They identified 30 riparian communities in total. Analysis of this data by combining types into broad categories shows that only some 19% of the total river length of the lower Coal can be described as intact or modified native vegetation, the latter often being invaded by a range of exotics in the understorey. Willow woodland and swamp comprises nearly half of the length of riparian zone length, with 36% made up of sown pasture, boxthorn/hawthorn or closed gorse shrubland.

Table 3.3. Lengths and proportions of riparian zone of the lower Coal River of differing vegetation types. Data analysed from Ecosynthesis (1999).

	km	%
Total	**40.3**	
Native	**3.3**	**8.2**
Degraded native	**4.6**	**11.4**
Willow	**17.9**	**44.4**
Other	**14.5**	**36.0**

Patches of remnant native riparian vegetation are present in areas that have been less disturbed by grazing and cropping, usually on the steeper rocky outcrops of valley sides (Askey-Doran 1993, Ecosynthesis 1999). They include species of *Eucalyptus*, *Acacia* (blackwood and silver wattle), *Leptospermum* (tea tree) and *Allocasuarina* (she-oak).

Overall, the conservation value of riparian vegetation of the lower Coal River is low, with most remnant communities associated with steeper sided and/or gorge features of the river.

3.6 Platypus

Reliable anecdotal observations confirm the presence of platypus (*Ornithorhynchus anatinus*) in the lower Coal River in the vicinity of Richmond and in the upper estuary below the downstream weir (T. Sloane pers. comm.). Platypus have also been observed in tributaries, with regular observations in White Kangaroo Rivulet.

The status of the population in terms of size, recruitment and of individuals in terms of health, condition, growth etc. is unknown. Platypus are widespread and common in Tasmania, across a wide variety of habitats which have experienced a range of impacts from development.

3.7 Overall biological condition

In summary, the Coal River contains a modified aquatic ecosystem, with:

- severely degraded riparian zones;
- impacted and depauperate macroinvertebrate communities which have lost some 30 to 60% of their expected diversity;
- a degraded fish community dominated by exotic species, and with clear evidence of a decline in diversity and abundance over the last 25 years;
- a limited recreational brown trout fishery which has declined in catch rates and visitation over the last 15 years;
- a platypus population of unknown status.

4. ENVIRONMENTAL CONDITION – RIVER WATER QUALITY

This section briefly describes the current knowledge of water quality and how it relates to flow. A detailed description of water quality issues in the Coal is not presented, as this is to be provided in the Coal River State of the Rivers report, currently being prepared (Krasnicki, DPIWE pers. comm.). Five main water quality issues are of potential concern in the Coal River – salinity, turbidity, nutrients, temperature and blue green algae.

4.1 Salinity

The Coal River valley has been identified as a high risk area for salinisation since at least the early 1980's (Finnigan 1995 and references therein), and high soil surface salinities and salt scalds have been identified at several locations, especially in the Pages Creek catchment (Todd 1999). Finnigan (1995) noted high conductivities in farm dams, with 15% of dams having summer conductivities >4 dS/cm. Todd (1999) observed high groundwater salinities in Pages Creek catchment, ranging between 2120 and 11900 mg/l.

To date there has been no comprehensive assessment of riverine salinity in the Coal River. Survey data provided by DPIWE for the Coal at Richmond are plotted along with and against flow in Figure 4.1. It can be seen that high flow events are associated with depressions in salinity, mainly due to dilution from upper catchment flows (Dam releases). Prolonged peaks in salinity, with conductivities ranging from 600 to 1300 microS/cm are observed during the winter-spring low flow season, a period when lower catchment groundwater and local tributary inputs would be high but river flows are low due to the absence of releases from Craigbourne Dam. A major peak in late September 2000 was due to undulated drainage of a salinised 180ML farm dam (Nocton Park, grid ref 535000, 5272300) into the Coal during low flows.

Overall, salinities in the lower Coal are high, especially when compared with state-wide figures from rivers (NLWRA 2000, Davies unpub. data). They also fall within the upper end of salinity trigger value ranges identified for lowland south-east Australian rivers within the ANZECC (2000) national water quality guidelines.

Salinity levels in the Coal are caused by naturally high salinity levels in soils, combined with groundwater and surface flows, potentially exacerbated by irrigation management. The pattern of salinity levels in the river itself is largely, however, driven by the pattern of flows, and is primarily controlled by Craigbourne Dam releases and secondarily by lower catchment tributary inputs.

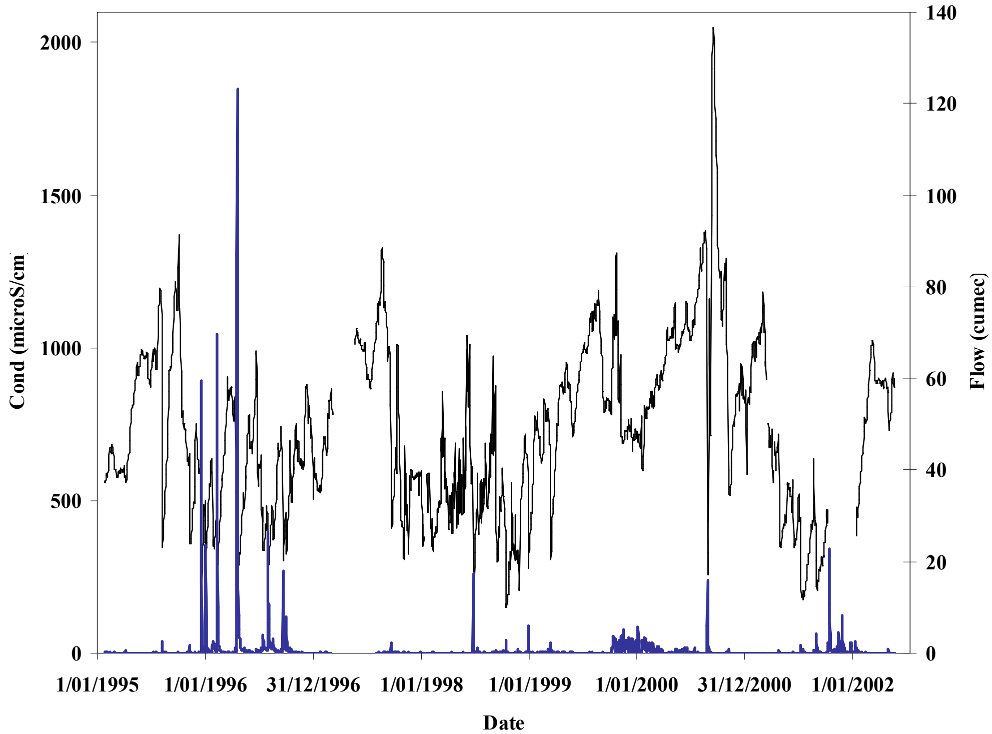
While high flows favour reduced salinity in the Coal, management of river salinity through dilution by release of Craigbourne Dam water is not a realistic option. The salinity problem must be managed at the source. There is also no direct evidence to date linking salinity in the Coal with impacts on the instream biota. Salinity is unlikely to be managed by the use of environmental flows, other than to assist minor flushing of salinity build-up in pools during winter-spring.

4.2 Turbidity

Turbidity levels vary considerably in the Coal River, both in space and time. Bennison (1975) reported turbidity varying between sites and between months in 1975, with a strong winter-spring seasonal peak associated with higher flows, especially in the Coal downstream of Mt Bains.

There are insufficient data available to allow an assessment of historical changes in turbidity levels, and recent recordings of turbidity at Richmond weir show a low background level coupled with very high turbidity peaks, many of which are driven by rainfall events (Figure 4.2). The turbidity response to flow is highly variable, suggesting that:

- there are local, tributary sources of high turbidity which contribute to river turbidity in response to rain events in the absence of major releases from Craigbourne Dam;
- releases from Craigbourne generally coincide with peaks in turbidity, but the relationship is highly variable, due to the mismatch between upper and lower catchment contributions to high flow events.



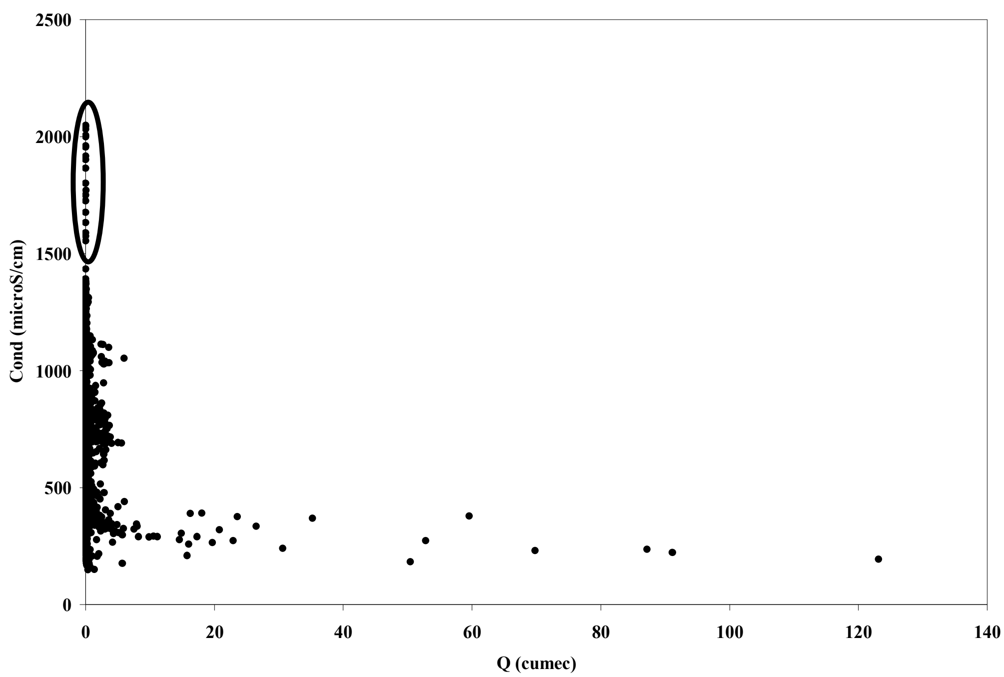


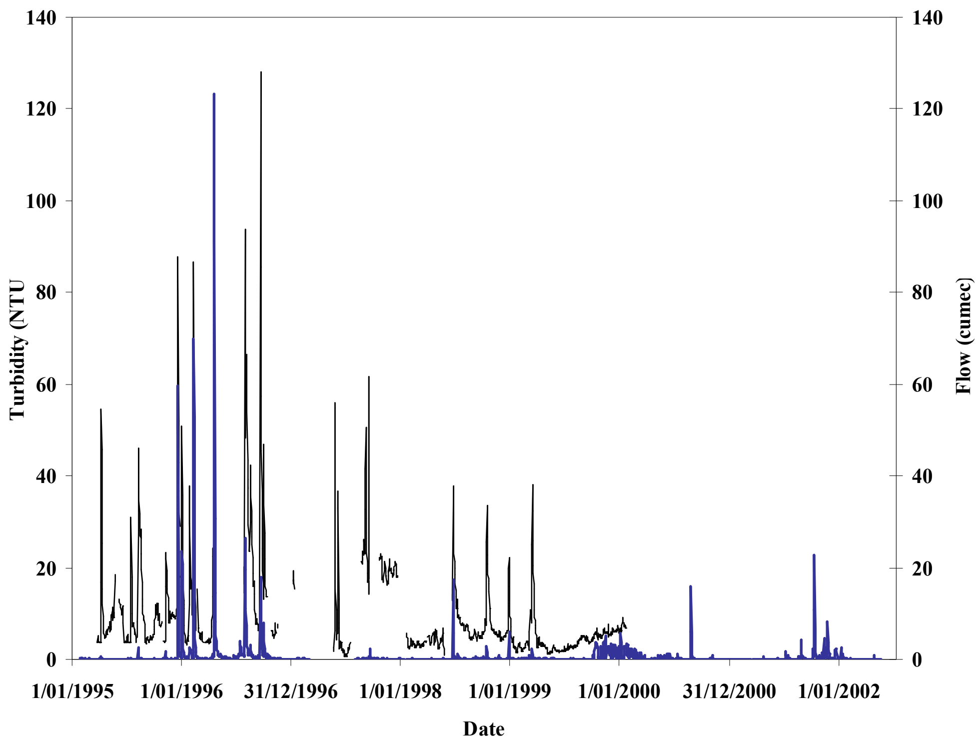
Figure 4.1. Salinity levels and flows in the Coal River at Richmond between 1995 and 2002, and the relationship between salinity and flow. Ellipse indicates high conductivities associated with September 2000 saline dam drainage event.

Values over 50 NTU fall above the upper limit of ANZECC (2000) trigger values for south-eastern Australian lowland streams and may be a cause for concern. Certainly the relatively high turbidity peaks observed in the lower Coal are likely to be associated with significant transport of fine sediments, but the significance of this cannot be assessed without evaluating a sediment budget for the catchment.

Modelled estimates of current sediment supply are comparable with other areas of Australia (Table 4.1, NLWRA 2000), but do not take into account historical rates during early catchment development. However, sediment transport is assessed as currently being some 11 times higher than prior to development. This, coupled with reduced sediment carrying capacity due to flow regulation below Craigbourne Dam, is consistent with observations of recent and on-going channel in-filling (see Section 2).

Table 4.1. Estimates of water borne erosion and sediment transport in Coal River (NLWRA 2002), compared with median values for other catchments in Australia.

Attribute	Unit	Basin value	Median Australia-wide value
Sediment supplied to rivers	t/yr	32163	166621
Sediment supply	t/ha/y	0.55	0.5
Hill slope erosion	%	34.08	14
Streambank erosion	%	22.78	30
Gully erosion	%	43.14	32
Length with riverbed deposition	proportion	0.09	0
European to Pre-European sediment	ratio	11	29
Sediment export to coast	t/y	15544	30062
Contribution of sediment to coast	t/ha/y	0.27	0.1
Sediment delivery	ratio	0.48	0.34



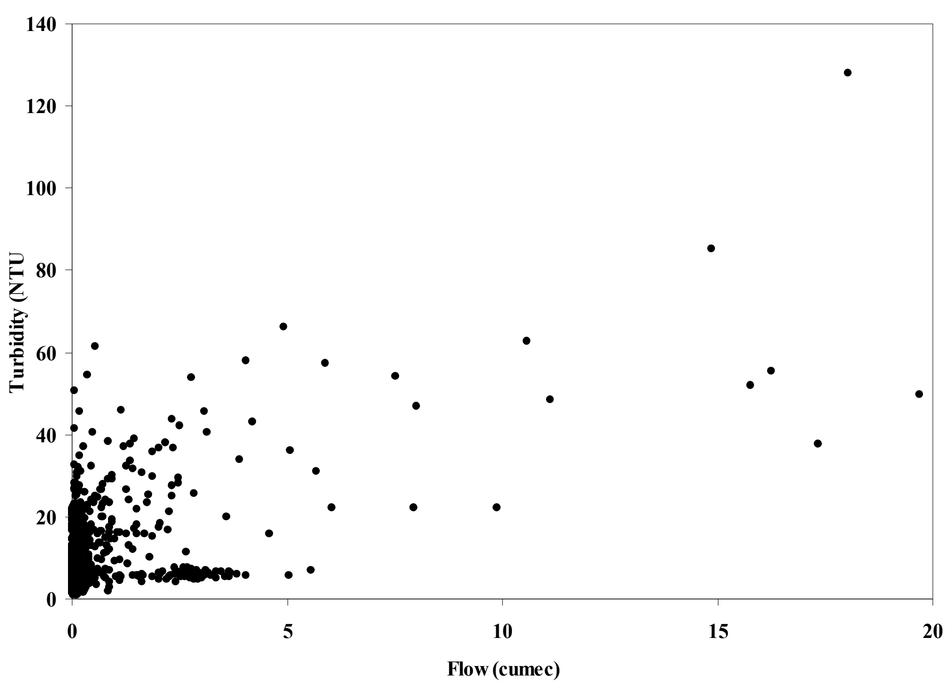


Figure 4.2. Turbidity and flow levels recorded in the Coal River at Richmond weir between 1995 and 2000, and the relationship between turbidity and flow.

4.3 Temperature

As for turbidity, stream temperatures are partially flow dependent. Figure 4.3 shows the recorded variation in temperature for the Coal at Richmond between 1995 and 2002. A damped seasonal cycle is evident, with short-term variation at least partially driven by high flow events. However, the relationship suggests that releases from Craigbourne generally coincide with depressions in temperature during summer, but the relationship is otherwise quite variable, due to the mismatch between upper and lower catchment contributions to high flow events and between reservoir and lower catchment surface water temperatures.

No assessment of the extent of river temperature modification by Craigbourne Dam and the regulated flow regime has been conducted. Management of stream temperatures using flow (eg Dam releases) is not feasible, especially in the absence of multiple level offtakes in Craigbourne Dam. Maximum temperatures are also not likely to be above lethal levels for native fish.

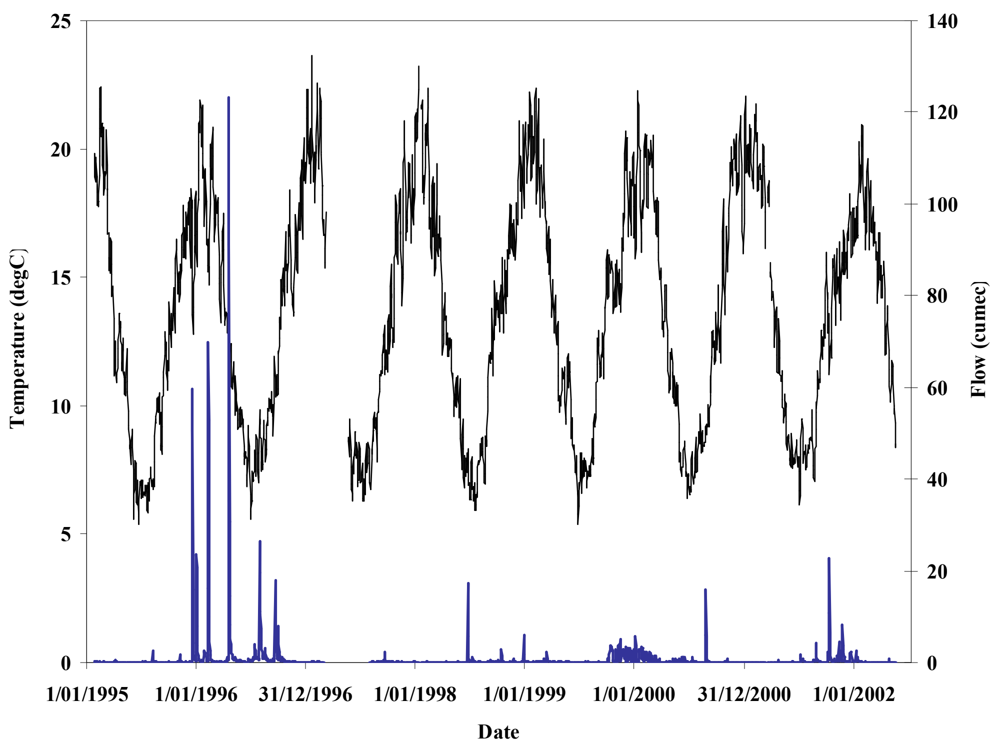


Figure 4.3. Temperatures and flows recorded in the Coal River at Richmond weir between 1995 and 2000. Note seasonal cycle with depressions associated with some flow peaks.

4.4 Nutrients and dissolved oxygen

No overview of the nutrient status of surface waters in the Coal catchment has been conducted to date. The estimated budget for the Coal derived under the National Land and Water Resources Audit (Table 4.3) is somewhat inaccurate as Craigbourne Dam was not included in the calculations. However, based on land-use, geology and relief, both phosphorus and nitrogen delivery rates to the estuary are significantly higher than under pre-development conditions, with the bulk of this being transported with sediments. Routine water quality monitoring results are shown in Table 4.2 for two sites. As expected, none of these analytes have a simple correlation with flow, since nutrient and dissolved oxygen (DO) dynamics are complex and only partially flow driven.

Nutrient delivery to the stream and through the drainage network to the estuary is largely seen as driven by high flow events (eg NLWRA 200 and associated references), and will be addressed through provision of high/flood flows.

DO levels appear satisfactory. However, no night-time DO data are available to assess if significant oxygen sags occur under low flows due to high levels of instream respiration.

Table 4.2. Median values for water quality analytes in the Coal River from monthly sampling between and Feb 1999 and Dec 2001 (from raw data provided by DPIWE). Note that DO data were collected during daylight hours.

Site	pH	Turbidity NTU	DO mg/l	DO % sat	Ammonia-N mg/l	Nitrate-N mg/l	Nitrite-N mg/l	TN mg/l	DRP mg/l	TP mg/l
Richmond weir	7.7	2.55	7.93	77	0.02	0.014	0.002	0.6165	0.004	0.0145
Downstream Craigbourne Dam	8.23	3.35	10.2	98	0.048	0.1	0.0045	0.907	0.008	0.034

Table 4.3. Nutrients delivered to rivers, floodplains, reservoirs and estuaries in Coal River (from NLWRA 2000).

Attribute	Unit	Basin value	Median Australia-wide value
Phosphorus from fine sediments	%	89	76
Phosphorus from point sources	%	0	0
Phosphorus – dissolved from diffuse sources	%	11	17
Phosphorus deposited on floodplain	%	26	30
Phosphorus deposited in reservoirs	%	0	0
Phosphorus delivered to estuaries	%	74	65
Phosphorus - total basin export	tP/y	11	46
Phosphorus - export rate	kgP/ha/yr	0.15	0.1
Phosphorus load - times pre-European	ratio	4.4	2.3
Phosphorus - dissolved to total	ratio	10	21
Nitrogen from sediments	%	74	44
Nitrogen from point sources	%	0	0
Nitrogen - dissolved from diffuse sources	%	26	51
Nitrogen deposited on floodplain	%	20	16
Nitrogen deposited in reservoirs	%	0	0
Nitrogen – denitrified	%	1	4
Nitrogen delivered to estuary	%	79	76
Nitrogen - total basin export	t/y	105	451
Nitrogen - export rate	kg/ha/y	1.5	1
Nitrogen load - times pre-European	ratio	2.7	1.7
Nitrogen - dissolved to total	ratio	27	65

4.5 Blue-Green algae

Blooms of the cyanobacteria *Anabaena circinalis* and *Microcystis aeroginosa* have become a problem in recent years in Craigbourne Dam and the Coal River. Significant blooms have occurred in the Dam on several occasions, with the first major bloom investigated in 1997 (Bobbi 1997). Dam releases resulted in high levels of *A. circinalis* cells, above the national Alert Level I as far downstream as 12 km . Detectable blue-green counts have been observed as far downstream as the Richmond weir, and cell counts increased during the 1997 bloom incident. An algal slick has been observed at the water surface between the two weirs at Richmond on several occasions. There are no data on specific flow conditions associated with high algal levels in the lower Coal, other than the existence of a release from Craigbourne Dam during blooms in the storage.

5. ENVIRONMENTAL CONDITION – ESTUARY AND PITT WATER

5.1 Physical description

Pitt Water is a relatively large, shallow estuary located approximately 20 km from the centre of Hobart (Figures 5.1 and 5.2). It covers an area of approximately 4150 ha and has a 78 km coastline. From a narrow entrance into Frederick Henry Bay, Pitt Water estuary extends for approximately 24 km to the second weir, south of Richmond. This weir effectively stops the movement of saline water any further up the Coal River. A number of rivulets and creeks flow into the estuary, with the Coal River being the largest. According to the Natural Land and Water Resources Audit 2000, Pitt Water is classified as wave-dominated and the description of this estuary in the Ozestuaries database, accessible at http://www.ozestuaries.org/oracle/ozestuaries/frame1.html, is shown in Table 5.1.

The catchment area of the Coal River and Pitt Water is approximately 890 km^2, of which approximately 620 km^2 is in the Coal River catchment and 270 km^2 only in the Pitt Water catchment (DPIWE 2001b). Mapping of the Pitt Water area in 2000 identified 1.27 km^2 of intertidal flats and 0.49 km^2 of saltmarsh or sand flats. The total area of Pitt Water was estimated to be approximately 60 km^2 (Ozestuaries database).

Much of the lower section of Pitt Water estuary contains extensive intertidal sand/mud flats with a narrow channel in the centre (see bathymetric map, Figure 5.3). A more detailed habitat map of the upper sections of Pitt Water prepared by the Tasmanian Aquaculture and Fisheries Institute in 2002 (Figure 5.4) shows the extensive region of very fine sediments in upper Pitt Water. Above this region, where the estuary is very narrow, the bedform consists of rock and cobblestones overlain by silt/clay sediments.

Aspects of the hydrodynamics of Pitt Water are summarised in Table 5.2 from Crawford *et al*. (1996). Estimates of mean water velocity varied from 0 to 20 cm/s in the top end of upper Pitt Water to approximately 160-180 cm/s at the mouth. The tidal range in the estuary is approximately 1 m.

The mouth of the estuary is very narrow due to a mid-bay spit (Seven Mile Beach) of alluvial material that formed as the sea level rose around 10,000 years ago. This resulted in flooding of the surrounding low-lying land and the formation of the Pitt Water estuary some 10,000-6,000 years ago. The underlying rock in most areas is Jurassic dolerite and extensive sand and mud flats formed from the deposition of silt transported into the estuary from rivers (DPIWE 2001b). The sedimentology and landforms of Pitt Water were described by Harris (1968).

Rainfall in the Pitt Water region is comparatively low, largely because it tends to be in a rain shadow from the predominantly westerly winds. Rainfall is spread relatively evenly throughout the year. Based on precipitation data for Richmond from the Bureau of Meteorology records, annual rainfall in the last twenty years has decreased relative to the twenty years prior, but this change is not markedly different from natural variation (Daley 1999). The mean annual rainfall at Richmond from 1915 to 1999 was 533.6 mm, and the median was 514.4 mm.

Figure 5.1. Aerial photograph of lower section of Pitt Water Estuary (Photograph from DPIWE).

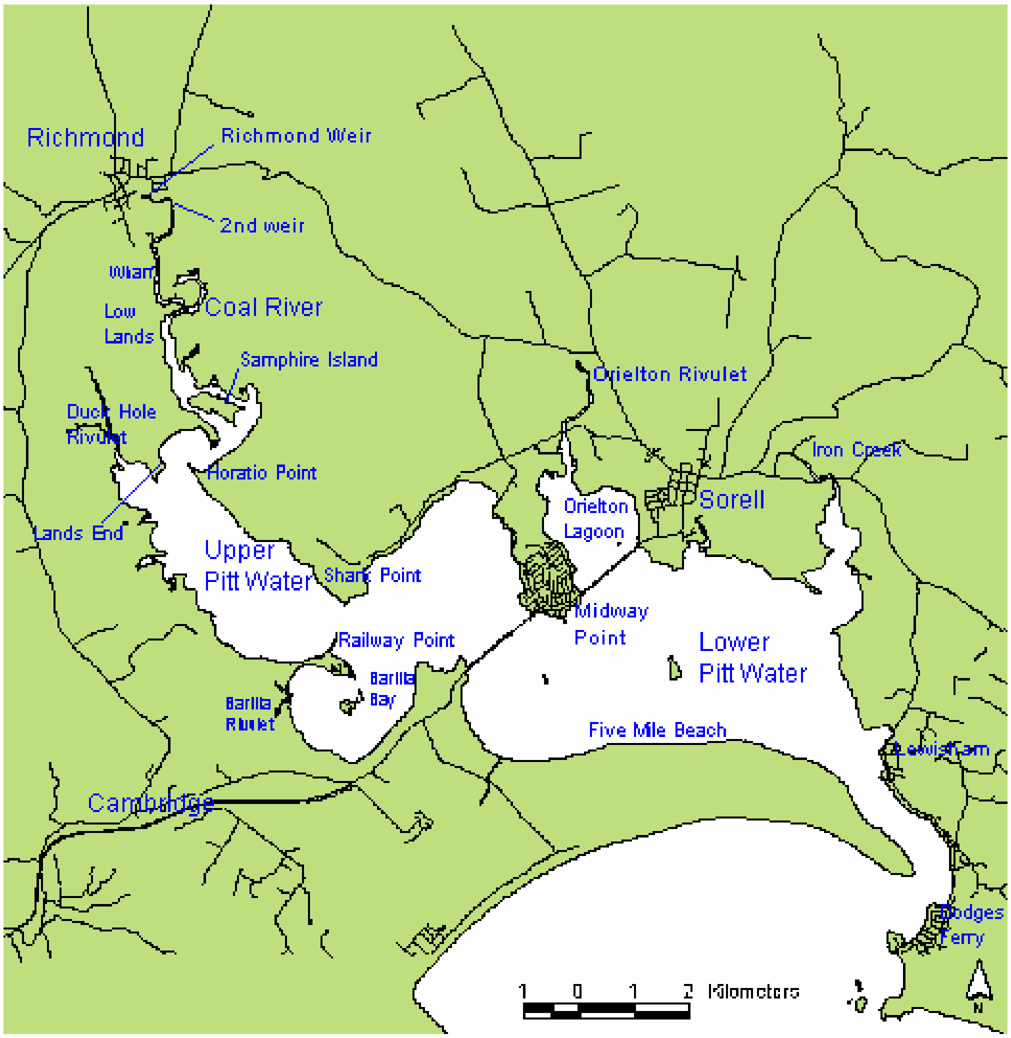


Figure 5.2. Map of Pitt Water estuary.

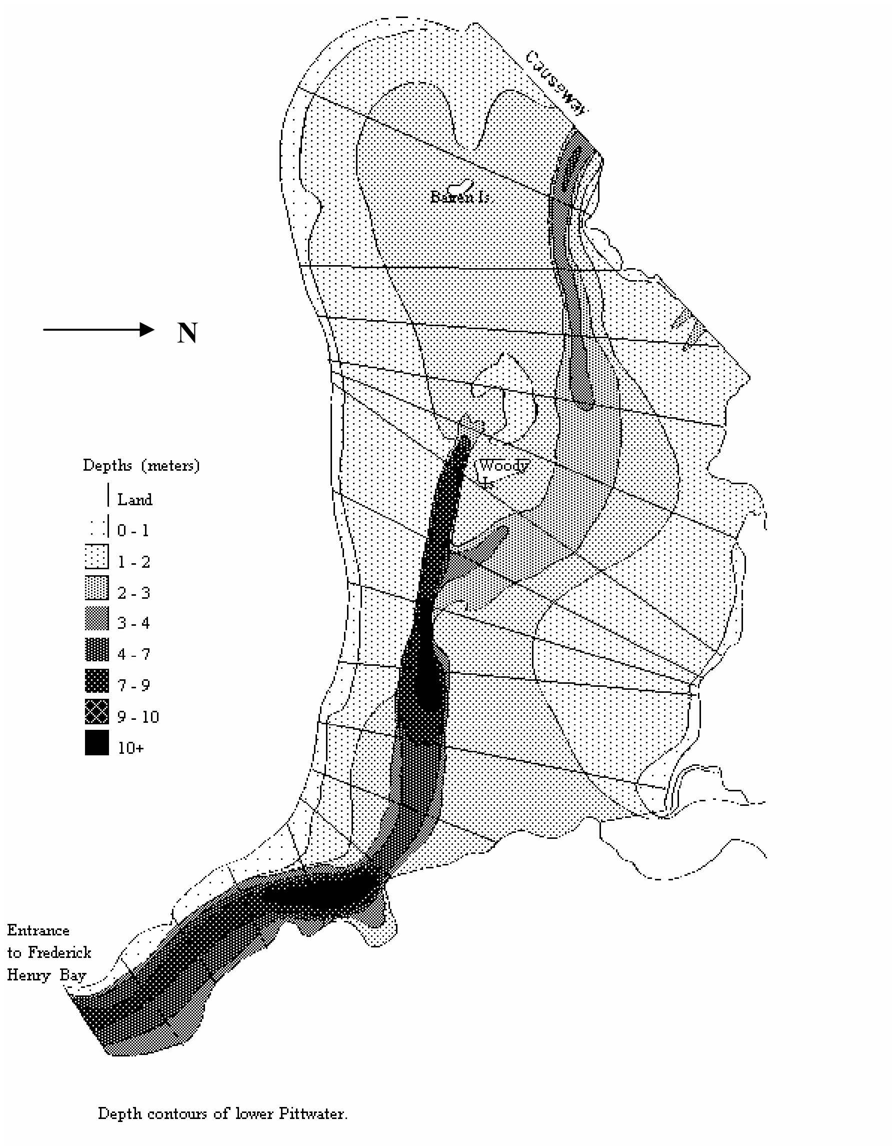


Figure 5.3 Bathymetric map of lower Pitt Water.

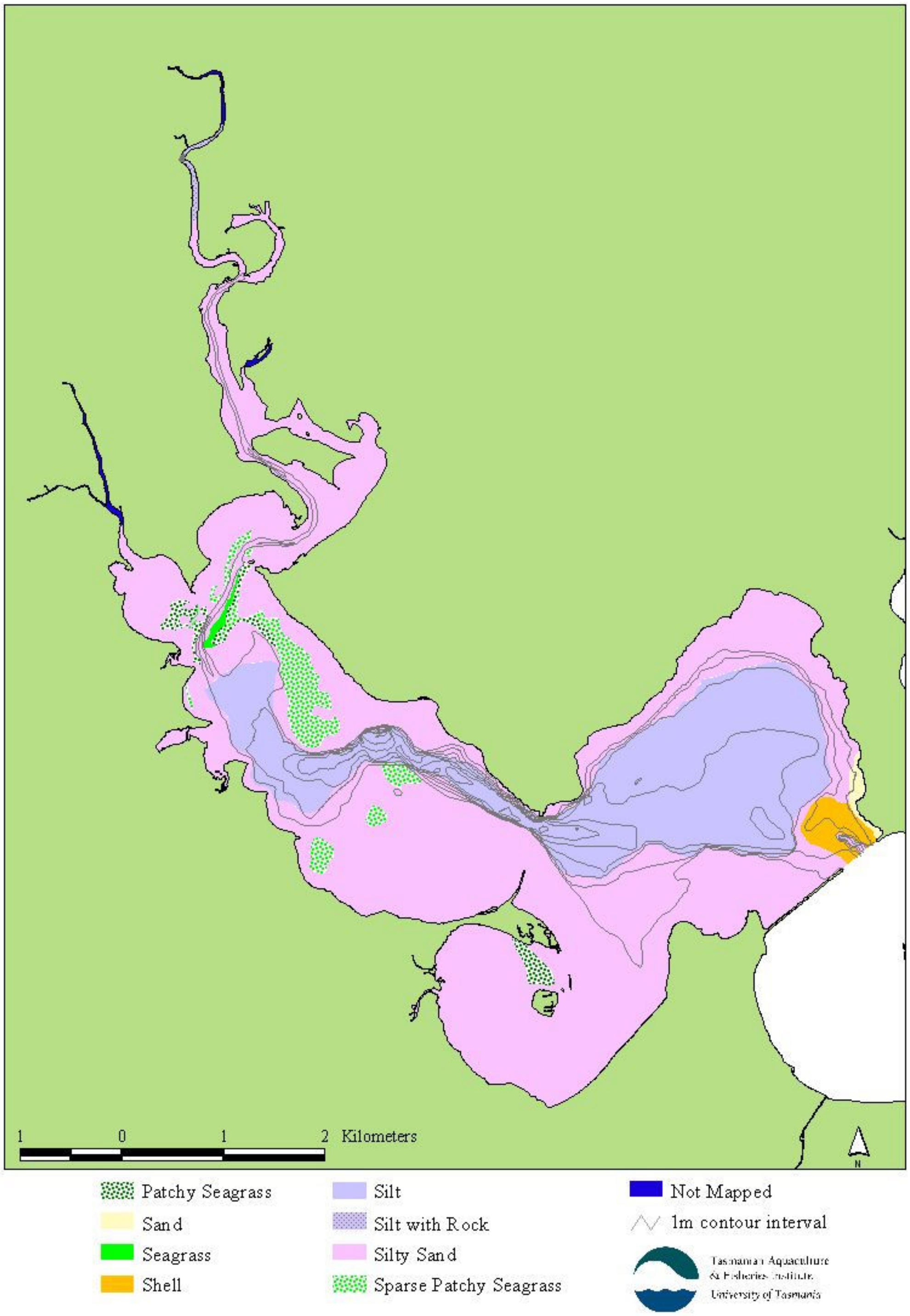


Figure 5.4. Habitat map of upper Pitt Water.

Table 5.1. Description of Pitt Water from the Ozestauries database.

OzEstuary ID	576
Name	PITT WATER
Location	SE
Current Classification	Severely Modified
Overall Condition	
Assessment Ranking	
STATE COMPONENT	
ECOSYSTEM INTEGRITY INDEX	
Eutrophication	
Chlorophyll a [median(80th)] HEAD	mean (1.4), 80th (1.8)
Chlorophyll a [median(80th)] MIDDLE	mean (1.3), 80th (1.7)
Chlorophyll a [median(80th)] MOUTH	mean (1.2), 80th (1.4)
Chlorophyll a [median(80th)] AVERAGE	mean (1.3)
Harmful algal blooms	
Turbidity [median(80th)]	
Turbidity (NTU or secchi depth) HEAD	mean (1.4 m), 80th (1.6 m)
Turbidity (NTU or secchi depth) MIDDLE	mean (1.9 m), 80th (2.2 m)
Turbidity (NTU or secchi depth) MOUTH	mean (3.4 m), 80th (3.9 m)
Turbidity (NTU or secchi depth) AVERAGE	mean (2.0 m)
Shellfish closures	Pitt Water was closed for 15 weeks in 2000 and 0 weeks in '97, 19 weeks in '98 and 2 weeks in '99.The main species affected: oysters.
Fish/bird kills	no data
Pathogens	no data
Faecal coliforms (no/100mL) [median(max)] 1998	1 (200)
Faecal coliforms (no/100mL) [median(max)] 1999	1 (99)
Faecal coliforms (no/100mL) [median(max)] 2000	1 (180)
Critical habitat loss	data unavailable
Anoxic and hypoxic events	no data
Invasive species	Crassostrea gigas

HABITAT INTEGRITY INDEX	Pitt Water was mapped in 2000 and the following facies areas were calculated: Intertidal flats~: 1273120 m²; Mangrove~: 0 m²; salt marsh or salt flats~: 492802 m² and tidal sand banks~: 0 m². The total facies area is ~ 59979066.7 m².
Seagrass species present	*Heterozostera tasmanica, Zostera muelleri, Ruppia* sp.
Seagrass coverage (area Ha)	84
Mangrove species present	
Saltmarsh coverage	
FISH HEALTH INDEX	
WATER QUALITY INDEX	
Nutrients [median(80th)]	
Ammonia (ug/L) AVERAGE	
Oxidised nitrogen (ug/L) HEAD	mean (1.7), 80th (2.4)
Oxidised nitrogen (ug/L) MIDDLE	mean (1.9), 80th (2.5)
Oxidised nitrogen (ug/L) MOUTH	mean (3.0), 80th (3.4)
Oxidised nitrogen (ug/L) AVERAGE	mean (2.1)
Phosphate (ug/L) HEAD	mean (9.1), 80th (10.0)
Phosphate (ug/L) MIDDLE	mean (8.7), 80th (10.4)
Phosphate (ug/L) MOUTH	mean (8.6), 80th (9.9)
Phosphate (ug/L) AVERAGE	mean (8.9)
Dissolved oxygen [median(20th)]	
Dissolved oxygen [surface] (%sat or mg/L) AVERAGE	
Dissolved oxygen [bottom] (%sat or mg/L) AVERAGE	
pH	
Heavy metals	no data
Salinity (mean ppt)	
Summer	
Surface head	
Surface middle	35.2
Surface mouth	34.5
Bottom head	
Bottom middle	
Bottom mouth	
Winter	
Surface head	1.3
Surface middle	28.6
Surface mouth	31.6
Bottom head	15.4
Bottom middle	
Bottom mouth	

Temperature (min - max)	8.2 - 19.9
Depth	1 - 3 m
SEDIMENT QUALITY INDEX	
PRESSURE COMPONENT	
UTILISATION INDEX	
Recreation Pressure	
Aesthetic & Amenity	
Yachting & Boating	windsurfing, boating, sailing
Shellfish	
Swimming	yes
Recreational Fishing	flathead, flounder
Infrastructure Pressure	
Sewage Treatment Plants	4 STPs: Cambridge (located: middle, permitted flow 125kL/day, secondary treatment), Orielton (located: middle, permitted flow 810kL/day, secondary treatment, chlorination), Sorell (located: middle, permitted flow 810kL/day, primary treatment, chlorination), Airport (located: middle, permitted flow 350kL/day, secondary treatment, UV)
Urbanisation and urban runoff	
Dredging	No routine maintenance dredging
Flow-modifying structures	present (1 dam ; 2 barrages)
Commercial Pressure	
Industry	yes
Aquaculture	Present 1.080 km2: oysters (436512 dozen) [1999]
Reclamation / Declamation	urban shoreline stabilisation
Commercial fishing	< 5 operators; total catch confidential
Tourism	none
Agriculture	
Habitat clearing	
Ports & Port Works	yes, commercial fishing, marina
Shipping Activity	none
SUSCEPTIBILITY INDEX	
RESPONSE COMPONENT	
Institutional Arrangements	Living Marine Resources Management Act 1995; National Parks and Wildlife Act 1970; Inland Fisheries Act 1995; Marine Farming Planning Act 1995
Management Actions	Fishery Management Plans; No netting; Shark nursery area; Marine Farming Development Plan; Pitt Water Nature Reserve
Community Initiatives	Midway Point Landcare; Orielton Lagoon Action Committee

Table 5.2. Hydrodynamics of Pitt Water (from the mouth to Lands End, excluding Orielton Lagoon) from Crawford et al (1996).

High water volume	101.8 million m^3
Low water volume	78.5 million m^3
Tidal prism	23.4 million m^3
Area	46.1 km^2
Flushing time	4.36 tidal cycles
Exchange rate	22.94%

5.2 Historic changes to flow in Pitt Water estuary and Coal River

Long term residents of Richmond advise that the Coal River used to be tidal as far as the Richmond bridge, which was constructed in 1823. In the 1800s sailing vessels regularly traversed Pitt Water and came part way up the Coal River. A 6 tonne vessel sailed to within half a mile of Richmond town and a 26 tonne sailing boat ran a regular service from the Port of Hobart to the wharf at Lowlands, 3 km downstream from Richmond (Jones 1973). However, siltation at the mouth of the Coal River as a result of the construction of the Sorell causeway and increased land clearance in the Coal River valley restricted the size of vessels that could navigate the river to small dinghies in the 1900s.

Causeways across Pitt Water from Tiger Head to Frogmore Peninsula (Midway Point) and between Frogmore Peninsula and Sorell were constructed in the early 1870s. The latter causeway, referred to as the Sorell causeway, was modified in 1953, resulting in limited water exchange between Pitt Water and Orielton Lagoon. Effects of the Sorell causeway and degradation of Orielton Lagoon have been documented by Brett (1992) and Kinhill (1993). Low water exchange resulted in highly variable salinity regimes and the decline and decomposition of many plant species. Filamentous algae flourished in the nutrient rich waters of the lagoon which received wastes from the Midway Point sewage treatment plant from 1969. Blooms of blue-green algae occurred in the late 1980's and early 1990's resulting in noxious odours. After a bloom of the toxic alga

Nodularia spumigena in 1992-93, remedial action was instigated. The sills on the causeway were lowered, allowing greater flushing of the lagoon, and the occurrence of algal blooms has subsequently declined (DPIWE 2001b).

A weir built below the Richmond Bridge in the early 1930's then became the upper limit for saline tidal waters. The upstream, freshwater side of the weir used to be a popular swimming and diving spot. However, local residents say that the water depth is now much shallower (~1 m) due to sediment deposition behind the wall. In 1992 a second weir was constructed below the historic weir at Richmond to further capture freshwater spilling over the Richmond weir. This weir effectively shifted the estuarine boundary further seaward. The stretch of water between these two weirs has now become infested with *Phragmites australis*, which is gradually choking this part of the river/former estuary. In June 2002 the water storage at this weir was increased by excavating a large hole on the upstream side. The rock rubble removed was dumped on the seaward side of the weir, with a narrow corridor left for fish passage.

Significant reduction in fresh water inputs to the estuary from Duck Hole Rivulet, Barilla Rivulet, and Pages Creek have also occurred with the construction of on-stream and off-stream dams. Water flows within these watercourses have been severely modified, to virtually little or no flows between major flood events.

As a consequence of water storage at Craigbourne Dam, water flow into Pitt Water has altered substantially. There is now a consistent low flow into Pitt Water during most months of the year (Figure 1.2). Thus summer flows into Pitt Water are often higher than those that would have occurred naturally prior to the development of the dam. Conversely, late autumn and winter flows are generally reduced, and fewer flood events occur (Figures 1.3 and 1.4, DPIWE 2001).

5.3 Water quality and nutrient input to Pitt Water estuary

There are three main sources of nutrient input into Pitt Water estuary - from sewage treatment plants (STPs), from exchange with oceanic waters and from freshwater inflow from the Coal River and smaller rivulets.

Crawford and Mitchell (1999) monitored nutrient levels (nitrates, nitrites, phosphates and silicates), chlorophyll a, temperature and salinity at 5-6 sites in Pitt Water from Marine just outside the entrance of the estuary to Shark Point in Upper Pitt Water for 39 months (Table 5.3). These results were collected as part of a study investigating the carrying capacity of several oyster growing areas in south eastern Tasmania.

Continued sampling at these sites and at an additional site towards the top end of upper Pitt Water for thirteen months by Mitchell (2001) found relatively low nutrient levels and chlorophyll a, except after heavy rains when chlorophyll a and nitrate (NO_X) concentrations were highest in the upper reaches of upper Pitt Water. Silicate concentrations, in particular were significantly higher after heavy rainfalls (Figure 5.5). The scatter about 34 ppt is due to resuspension of sediments (predominantly wind driven) at shallow sites.

Temperature, salinity, nitrate and phosphate data collected in upper Pitt Water by CSIRO in most months in 1949-50 and 1954-56 were similar in overall values to those recorded in 1991-94 (CSIRO 1952, CSIRO 1956, CSIRO 1957b, CSIRO 1957a). Nitrates in 1956 were higher than average, but not dissimilar to the results for the 12 months from August 1991 to July 1992.

Water quality data have only been collected sporadically from the lower regions of the Coal River catchment, and almost entirely during low flow and low rainfall periods. Results for N and P species from the Richmond Weir and Duck Hole Rivulet at Colebrook Road, approximately 3 km from the entrance of this rivulet into Pitt Water estuary, collected by DPIWE from February 1999 to December 2001 as part of their State of River (SOR) assessment are summarised in Table 5.4. These samples were collected during conditions of low to little water flow in the Coal River, range 0 to 3 cumec, and low rainfall in the days prior to sampling.

Table 5.3. Mean annual values for several physical parameters at sites in Upper and Lower Pitt Water (data from Crawford and Mitchell 1999).

Date	Station	Temp °C	Salinity (ppt)	Chl a (μg/L)	NOX (μg/L)	NO3 (μg/L)	NO2 (μg/L)	PO4 (μg/L)	SiO4 (μg/L)
1991	Marine	12.00	33.63	1.81	14.80	12.58	2.22	9.18	-
	Lewisham	12.00	33.61	1.52	9.00	6.22	2.78	6.90	-
	Causeway	11.96	33.90	2.64	6.20	4.46	1.74	6.90	-
	Barilla	11.79	34.10	2.17	12.00	9.68	2.33	6.55	-
	Shark Pt	12.09	33.93	2.89	14.80	11.98	2.82	7.30	-
	mean	**11.96**	**33.88**	**2.30**	**10.50**	**8.09**	**2.42**	**6.91**	-
1992	Marine	13.05	34.13	2.18	7.32	6.13	1.19	11.42	-
	Lewisham	12.93	34.28	2.33	4.80	3.46	1.34	8.45	-
	Causeway	13.05	34.39	2.64	4.68	3.47	1.21	8.59	-
	Barilla	12.64	34.62	2.42	4.93	3.69	1.24	7.75	-
	Shark Pt	12.88	34.48	2.96	9.00	7.98	1.03	10.03	-
	mean	**12.87**	**34.44**	**2.59**	**5.85**	**4.65**	**1.20**	**8.71**	-
1993	Marine	13.87	34.24	1.47	3.08	2.77	0.31	9.44	32.25
	Lewisham	13.82	34.43	1.59	2.24	1.95	0.29	8.77	44.35
	Woody Is	15.45	34.66	2.76	0.75	0.50	0.25	8.25	174.00
	Causeway	14.04	34.96	2.70	1.55	1.33	0.22	8.87	172.00
	Barilla	14.09	35.41	1.89	2.19	1.91	0.28	8.96	185.00
	Shark Pt	14.10	35.13	2.62	1.96	1.74	0.22	9.59	211.00
	mean	**14.30**	**34.92**	**2.31**	**1.74**	**1.49**	**0.25**	**8.89**	**157.27**
1994	Marine	12.46	33.58	4.08	1.80	1.41	0.16	9.30	82.70
	Lewisham	12.41	33.54	3.73	1.71	1.71	0.16	8.93	93.95
	Woody Is	12.70	33.43	4.39	1.58	1.86	0.04	9.54	137.11
	Causeway	12.48	33.53	4.71	1.00	1.11	0.03	9.03	134.74
	Barilla	12.35	34.04	3.62	0.99	0.93	0.04	8.93	134.48
	Shark Pt	11.93	33.84	4.87	0.94	1.31	0.06	9.37	144.14
	mean	**12.37**	**33.68**	**4.26**	**1.24**	**1.39**	**0.07**	**9.16**	**128.88**

Note: Number of samples analysed varied between years.
Means are for Pitt Water and do not include the Marine Station.
Sampling at Woody Island and silicate analysis commenced in November 1993

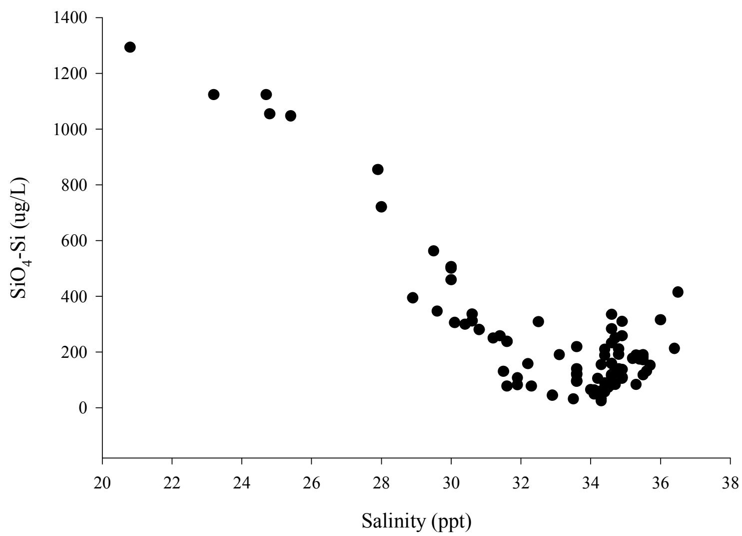


Figure 5.5. Silica concentration at different salinity levels for Pitt Water using all data at seven sites from Feb 95 – March 96 (Mitchell 2001).

Table 5.4. Average, median, maximum and minimum nitrate-N (µg/L), total N (µg/L), dissolved reactive phosphorous (phosphate) (µg/L) and total P (µg/L) concentrations in the Coal River at Duck Hole Rivulet and the Richmond Weir.

	Nitrate Duck Hole Rv.	**Nitrate** Richmond Weir	**Total N** Duck Hole Rv.	**Total N** Richmond Weir	**Phosphate** Duck Hole Rv.	**Phosphate** Richmond Weir	**Total P** Duck Hole Rv.	**Total P** Richmond Weir
Average	18	27	1287	655	110	5	228	16
Median	4	14	948	617	16	4	54	15
Maximum	171	244	4030	1380	1800	17	3080	56
Minimum	1	1	380	399	2	2	5	2
N	33	36	34	36	34	36	34	36

Median nitrate values were low at both Duck Hole Rivulet and Richmond, although one very high value was recorded at the Richmond Weir. At this time, although flow was minimal, turbidity was high, suggesting unusual disturbance of the river. Total N, however, was high at Richmond weir and very high at Duck Hole Rivulet. Ammonium levels were generally low during this period (data not shown), indicating that the high total N values were due to organic and particulate fractions. As total N values were highest when turbidity levels were also high, inorganic particulate matter is likely to be a major contributor to the high N concentrations.

Similar to nitrates, median phosphate concentrations were low at both sites. Median total phosphorus values were low at Richmond Weir and moderately higher at Duck Hole Rivulet. Extremely high values for both phosphate and total P were recorded at Duck Hole Rivulet on one occasion. At this time turbidity levels were also abnormally high suggesting high levels of particulate matter and the results were probably anomalous.

Unfortunately, few results are available during moderate to relatively high rainfalls or river flows. This makes it difficult to accurately assess nutrient loadings and trends within the catchment, especially when nutrient loads tend to be tightly linked to high flow events. Two samples collected in February and April 1996 during flood conditions at the Richmond weir had markedly higher turbidity levels (mean 67 NTU). Nitrate and total N values were much higher than those recorded in the previous year (mean 120 and 1450 microg/l) and were still relatively high several months later. Phosphate and total P concentrations were also much higher (mean 20 and 110 microg/l) than previous recordings but had returned to low values one month later. Flows on these two occasion were 16.5 and 35 cumec, markedly higher than the flows recorded during the routine SOR sampling, with results presented in Table 5.4.

As expected, water quality data from the Coal River at Richmond were much more variable than from upper and lower Pitt Water, primarily because oceanic waters buffer the lower estuary from major environmental change. Mean nitrate concentrations were higher at Richmond Weir, whilst phosphate concentrations were lower than in lower Pitt Water. The maximum values of total N and P at both the

Richmond Weir and Duck Hole Rivulet indicate that very high nutrient concentrations can be washed into Pitt Water estuary during flood conditions.

Four waste water treatment plants (WWTP's) discharge into the middle section of Pitt Water. Cambridge (secondary treatment, permitted flow 125kL/day into Barilla Bay), Midway Point (secondary treatment, chlorination, permitted flow 810 kL/day, Sorell (primary treatment, chlorination, permitted flow 810 kL/day) and Hobart Airport (secondary treatment, disinfection prior to discharge into a drain which flows approximately 1.5 km before discharge into lower Pitt Water at Five Mile Beach, permitted flow 350kL/day). Currently, Cambridge WWTP has no outfall as evaporation rates from the settling ponds are greater than inputs. A WWTP located near Richmond consists of three ponds with secondary treatment and disinfection. A small WWTP at Penna treats effluent from local subdivisions.

Daily total nitrogen and phosphorus loads from the major WWTPs into Pitt Water estuary are shown in Table 5.5. Estimates for the Midway Point and Sorell WWTPs suggest that wet weather flow loads may be three times greater than average dry weather flows (pers. com. Manager Environment and Development, Sorell Council)

Some urban stormwater also flows to Pitt Water. Midway Point has six piped storm water outlets into Orielton Lagoon and Sorell township has two piped outlets into the lagoon. Additionally, a number of residences in the Pitt Water Estuary area rely on septic tanks for the treatment of wastes. However, nutrients from these sources are much lower than from the three major sources. Wastewater re-use schemes are currently being developed by both the Sorell and Clarence Councils.

The relative contribution of the three main sources of nutrients into Pitt Water estuary was calculated from annual average flows and nutrient inputs from each source into the estuarine system (Table 5.6). Although these calculations are based on gross averages, they clearly show that during conditions of low flow from the Coal River, the majority of the nutrients are originating from oceanic sources. However, during flood conditions, the relative contribution of nutrients in freshwater inflow is much higher, especially for nitrogen.

Table 5.5. Flow rate and average daily loads of nitrogen and phosphorous from the four main sewage treatment plants in Pitt Water estuary.

STP	Flow rate (kL/d)	Average daily **TN** (kg/d ± sd)	Average daily TP (kg/d ± sd)
Richmond	85	1.51 ± 0.78	1.22 ± 0.30
Midway Point	600	3.0	3.0
Sorell	400	1.8	2.9
Cambridge	0	0	0

Table 5.6. Average flows and daily nutrient input into Pitt Water estuary from the Coal River at the Richmond Weir, from STPs and from tidal inflow of oceanic waters.

	Q cumec	Q m^3 per day	P Load kg P / day	N Load kg N / day
Richmond Weir	**0.605**	**52,230**	**836**	**34,211**
(± sd)	± 4.75	± 410,132	± 6,562	± 268,637
STP		**1,085**	**7**	**6**
Tidal Input		**21,165,237**	**211,652**	**124,875**
(± sd)			± 13,547	± 7,993
Tidal Output		**17,094,989**	**153,855**	**51,285**
(± sd)			± 12,193	± 4,064
Total input /day			**212,495**	**159,092**
%Marine			**99.6**	**78.5**
Total export /day			**153,855**	**51.285**
Size of sink			**58,640**	**107,807**
Ratio input/export			**1.38**	**3.10**

Given that nutrient inputs are considerably higher than exports (i.e. 138% higher for phosphates and 310% higher for nitrates), the estuary may be vulnerable to eutrophication if the capacity of any nutrient sinks are exceeded, especially in upper Pitt Water where the exchange rate is low. At present, no accurate quantification of the size of such sinks can be determined. In particular, the amount of nitrogen lost from the system by denitrification is not known. Consequently, a precautionary approach should be adopted and additional nutrient inputs limited until the nutrient loads and fluxes are more fully understood.

The water quality (bacterial counts) in upper Pitt Water is also regularly monitored as part of the Tasmanian Shellfish Quality Assurance Program (TSQAP), to ensure that commercial shellfish are safe for human consumption. Bacterial counts have been found to be correlated with rainfall, as high numbers of bacteria are washed into estuaries from land runoff and additional flows from WWTPs after heavy rain. Data collected as part of the TSQAP Program showed that before Craigbourne Dam was commissioned, rainfall greater than 20 mm, which resulted in a salinity of approximately 27 ppt at Barilla Bay, Upper Pitt Water, occurred six times per year in both 1985 and 1986. During such flood events, bacterial counts in the oyster growing area reached unacceptable levels and the farms had to be closed to harvesting due to public health concerns. As a consequence, the Pitt Water oyster growing area was classified as “Approved Conditional" by TSQAP (Brown and Mitchell 1992). However, an assessment of the water quality data from 1986 to 1992 showed a marked improvement in water quality and the area was reclassified as “Approved", allowing the oysters to be marketed from the area at any time. The most likely factor in the improved water quality was the storage of water in the Craigbourne Dam (Brown and Mitchell 1992). During this time there was no major flooding in Pitt Water, and runoff carrying contamination (and nutrients) to the growing area had been significantly reduced. Although the reduction in flow improved the bacterial quality of the water, the oyster farmers felt that this was outweighed by the loss in primary production in the area, and hence algal food supplies for the oysters. Since 1992, however, there have been several floods into Pitt Water.

5.4 Biology of Pitt Water

Knowledge of the flora and fauna of Pitt Water is patchy and has developed from a variety of unrelated studies. The flora and fauna of the Pitt Water - Orielton Lagoon Ramsar site is discussed in the management plan for this region (DPIWE 2001b). Invertebrate infauna (35 species) in shallow, soft sediments at several sites in Pitt Water were recorded by Edgar *et al*. (1999), and fishes in shallow water are described by Last (1983). Information on the aquatic fauna and flora around Midway Point in lower Pitt Water has been recorded for some 40 years by local resident Geoff Prestedge. He collated his notes in 1995 (Prestedge 1995) and continues to provide updates on his observations. He also studied the endemic viviparous seastar *Patiriella vivipara* in some detail in Pitt Water (Prestedge 1998).

As part of the Sorell Causeway bridge replacement project, Aquenal (2000) comprehensively reviewed the literature on the aquatic flora and fauna of Pitt Water and surveyed the marine biota in the vicinity of the Sorell Causeway bridge (western causeway) in 2000. 54 species were recorded in total, with 39 motile and 15 sessile species. Aquenal (2000) compiled a list of all invertebrate species and their relative levels of abundance that have been found in several studies in Pitt Water. Aquenal (2000) also listed the 40+ species of fish that have been recorded in Pitt Water by Geoff Prestedge. These species were all marine, except for three which could be classified as estuarine/marine, yellow-eye mullet *Aldrichetta forsteri*, sea mullet *Mugil cephalus* and smooth toadfish *Torquigener glaber.* However, no systematic and comprehensive studies of aquatic floral and faunal communities in Pittwater have been conducted, thus major gaps exist in our knowledge of the biota of this region.

Kirkpatrick and Glassby (1981) described the saltmarsh vegetation in Pitt Water as part of a study of saltmarsh communities around Tasmania, and Richardson *et al.* (1998) investigated the invertebrate fauna of Tasmanian saltmarshes, in particular the crustacean and mollusc fauna.

The composition of the phytoplankton around oyster farms in upper Pitt Water was investigated by Hallegraeff and Tyler (1987) from March 1985 until April 1986, just prior to the Craigbourne Dam coming on line. Diatoms and nannoplankton (< 20 micron) flagellates dominated the phytoplankton, and the diatom species *Asterionella glacialis, Chaetocerus spp., Nitzschia closterium* and *N. pungens* reached bloom proportions (10^6cells/ml) in March 1985 and December/February 1986. The Pitt Water phytoplankton community was similar to that in Storm Bay, except for a high percentage of benthic diatom species resuspended from bottom sediments and a low abundance of large dinoflagellates in Pitt Water. Stomachs of freshly opened oysters contained mainly diatom cells and pigment content that varied considerably less than algal pigments in the water column, indicating that the oysters were selectively feeding on specific algal species.

Very little information is available for the upper reaches of the estuary between Lands End and Richmond. Extensive land clearing has occurred close to the edge along most of this stretch of the estuary, with little or no stabilizing vegetation present. This has often included clearing of upper salt marsh and associated terrestrial vegetation, such as casuarinas. The African boxthorn (*Lycium ferocissimum*), an invasive introduced weed species, occurs along many parts of this stretch of the estuary, along with extensive areas of gorse (*Ulex europaeus*), particularly along the river bank north of the second weir.

6. ENVIRONMENTAL VALUES AND ASSETS OF THE COAL RIVER – PITT WATER SYSTEM

6.1 Coal River

Key environmental assets of the Coal River include:

- aquatic fauna – particularly the native fish populations
- the platypus population;
- aquatic flora – particularly the pool macrophyte communities;
- riparian vegetation – particularly remnant vegetation;
- the brown trout recreational fishery;
- aesthetic values – particularly high water clarity without algal blooms/scum.

Many of these assets are at least partially degraded due to development within the catchment. A primary aim of environmental flow management for the lower Coal must be the prevention of further degradation that may result from intensification of flow regulation, noteably reduced base flows, loss of high/flood flows, and further imbalance in the seasonality in flows.

6.1.1 Conservation status

The degraded nature of the instream and riparian environment suggests that, apart from platypus, the conservation significance of the river has been significantly compromised. In addition, floodplain backwaters, pools and ponds are frequently highly saline, though their biological status is unknown.

No threatened fauna have been identified from the lower Coal River to date.

6.1.2 Aquatic habitats

Most aquatic habitats of the lower Coal have been impacted by down cutting and widening of the channel (probably in response to historical land clearing, see Section 2), and subsequent sediment deposition and channel contraction, particularly following construction of Craigbourne Dam. In addition, the invasion of exotic plants into the riparian zone, particularly willows, has been associated with loss of instream macrophyte habitat and channel narrowing. The dominant habitats are pools, runs and riffles, though the degree to which they are intact varies considerably along the river (Section 2). Floodplain pools and ponds also exist which connect intermittently to the channel.

A primary management aim must be to maintain the diversity of aquatic habitats, as well as the connectivity and water quality of pools under low flows.

6.1.3 Riverine Protected Environmental Values (PEV's)

An initial set of community water values were determined by DPIWE at a workshop in 1999 (Table 6.1). These were subsequently followed by community determination of a set of water quality and water quantity protected environmental values (PEV's) for the Coal catchment as part of PEV setting for the Southern Midlands catchments under the State Policy on Water Quality Management 1997 (Table 6.2). Under this Act, these are the values or uses which should be protected through management of water quality and quantity.

Both sets of values identify a number of flow-related issues and management priorities. They articulate a desire by the community to see aquatic ecosystems and their biota and the recreational fishery to be maintained, as well as aesthetic values associated with water quality and flow. There is a recognition, however, that the Coal downstream of Craigbourne is also an "irrigation channel". This implies the need to maintain ecosystem values within the constraint of irrigation supply via the river channel.

Table 6.1 Water Values identified for the Coal River (DPIWE Community Workshop held on 12/7/99 - Old Richmond Council Chambers).

BROAD WATER VALUE CATEGORIES	SPECIFIC WATER VALUES PRIORITISATION OF VALUES	PRIORITISATION OF VALUES
1. Ecosystem	• Reduce impact of Crack Willow.	3
	• Improve native riparian vegetation.	3
	• **Improve the quality of recreational fish species.**	**4**
	• Improve water quality.	1
	• Control of blue-green algae in the mainstream.	1
	• Ban sewage input into the waterway.	1
	• Treatment of blue-green algae in Craigbourne dam.	1
	• **Determine flow requirements for the estuary.**	**2**
	• **Maintain minimum flows in the river.**	**4**
	• Address excessive litter problem above and below the Richmond weir.	4
	• **Provision of adequate environmental flows.**	**2**
	• Address any pesticide issues in catchment waterways.	4
	∗ **Improve seasonal (winter) flood flows for flushing.**	
	∗ Improve ponds and wetlands for fish and bird habitat.	
2. Recreational	• Improve water quality for swimming.	4
	• Maintain wild duck hunting on Craigbourne dam.	5
	• **Maintain recreational fisheries.**	**3**
	• **Maintain suitable wildlife species for nature appreciation.**	**2**
	• Maintain suitable conditions for windsurfing on Pitt Water.	5
	• **Maintain the aesthetic value of the portion of river flowing through Richmond for tourism purposes.**	**1**
	∗ **Improve trout, redfin and eel fishery below Craigbourne dam.**	
	∗ Improve dam water quality for trout fishery.	
	∗ Maintain duck habitat for hunting purposes.	

3. Physical Landscape	• **Maintain the current watercourse.** • Maintain and improve riparian vegetation for erosion protection. • Management of exotic weeds. • **Control of excessive sediment build-up in the river and estuary.** * Improve ponds and wetlands.	**2** 2 3 **1**
4. Aesthetic	• **Control of excessive sediment build-up in the upper estuary.** • **Maintain suitable water levels for the pool environment above the Richmond weir.** • Where necessary improve or maintain native streamside vegetation. • Suitably manage exotic vegetation around the Richmond section of the river. * Improve appearance of river and its surrounds below the dam.	**2** **3** 1 1

Note: asterisks indicate additions received independently of the meeting, for which prioritisation was not possible.

Table 6.2. Water quantity Protected Environmental values identified for wetlands and waterways in the Southern Midlands catchments at the Oatlands regional community workshop that are related to flow management (DPIWE 2001). Note comment on Coal as an irrigation channel in bold.

1. Ecosystem values

- Platypus across the whole catchment
- Native water rat across the whole catchment. *Hydromys chrysogaste*r. Partly protected species. Considered secure.
- Small shrimps of Family *Atyidae* Genus *Paraty*a. Reasonably widespread in lowland dams & standing freshwaters. The Coal River near Campania is specifically mentioned.
- Instream habitat prevented from degradation.
- Maintain native riparian vegetation. Changed flows may expose beds, encourage silting and weed invasion.
- Maintaining series of pools for habitat across region.
- Natural flow regimes for all catchments and tributaries, **except Coal River below Craigbourne Dam which is designated irrigation channel.**

2. Physical landscape values

- The integrity of stream bank is important to avoid soil loss and turbid water.
- Maintaining native riparian vegetation is important. Changed flows may expose beds, encourage silting and weed invasion.

3. Consumptive or non-consumptive values

- Maintaining series of pools for stock watering
- Domestic use (non-drinking) for all catchments. Coal River & Wallaby Rvt. specifically mentioned.
- Irrigation across all catchments
- Stock Watering across all catchments

4. Recreational values

- Duck Hunting across all catchments. Coal River & Craigbourne Dam specifically mentioned.
- Fishing across all catchments.

5. Aesthetic landscape values

- Coal River below Craigbourne is an attractive feature in intensive agriculture zone.
- Maintain native riparian vegetation is important. Changed flows may expose beds, encourage silting and weed invasion – destroying aesthetic appeal
- Pool sequences or holes attractive feature of waterways.

6.2 Pitt Water

Environmental assets, or special features of Pitt Water include:

- Threatened and endangered flora and fauna (5 plant species, 5 bird species, live-bearing seastar, and a frog.)
- RAMSAR wetlands
- Aquatic habitats, particularly seagrasses and intertidal sand and mud flats
- Shellfish aquaculture
- Commercial fishing and nursery area for school and gummy shark
- Recreational activities, including swimming, water skiing, boating, wind surfing and fishing
- Aesthetic values - high scenic value and tourism potential

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6.2.1 Conservation assets

Threatened flora and fauna.

Pitt Water Estuary can be classified as being of high conservation significance primarily because of the presence of threatened and endangered species in the region.

Pitt Water contains five species of plants that are listed in accordance with the Threatened Species Protection Act 1995. One species, the daisy, *Calocephalus citreus* (lemon beauty-head), which occurs near Orielton Lagoon, is listed as endangered. The other four species, *Lepilaena preissii* (slender water-mat), *Limonium australe* (sea lavender), *Potamogeton pectinatus* (fennel pondweed) and *Wilsonia humilis* (silky wilsonia) are listed as rare because they occur in less than twenty 10x10 km grid squares throughout Tasmania (DPIWE 2001b). Pitt Water Nature Reserve is the only reserve where the slender water-mat and silky wilsonia occur, and fennel pondweed and sea lavender are found in only two reserves.

Orielton Lagoon has been found to contain many species of bryophytes which are of high conservation value. Although not currently listed under the Threatened Species Protection Act 1995, many of the species identified meet the criteria for threatened status under the ICUN (DPIWE 2001b).

Fauna which occur in the Pitt Water estuary region and are listed as threatened or endangered under the Tasmanian Threatened Species Protection Act 1995 include:

Patiriella vivipara (live-bearing seastar)	endangered
Sterna albifrons sinensis (little tern)	endangered
Lathamus discolor (swift parrot)	vulnerable
Podiceps cristatus (great crested grebe)	rare
Sterna nereis (fairy tern)	rare
Aquila audax fleayi (wedge tailed eagle)	endangered
Litoria raniformis (green and gold frog)	vulnerable

Pitt Water contains the largest known concentration of the small endemic seastar, *Patiriella vivipara*; one of only three viviparous seastars known worldwide. The total recorded habitat of this species is only approximately 3 ha. It occurs in rocky areas of the intertidal zone to a maximum depth of 1.5 m (Prestedge 1998). This species is susceptible to changes in habitat, especially from urbanisation and pollution. Prestedge (1998) found that the distribution of this species has declined significantly in Pitt Water and several large colonies in upper Pitt Water have disappeared over the last twenty years. He suggests that this decline in range and abundance is related to anthropogenic impacts on water quality, in particular increased nutrients and sedimentation.

Orielton Lagoon is also one of the few sites where the great crested grebe is regularly found.

***RAMSAR wetlands*.**

Pitt Water is also of high conservation value because of the saltmarshes that occur in the estuary. This habitat has been recognised as being of high ecological significance. Much of the area around Pitt Water is included on the register of the National Estate for its natural values and was placed on the list of Wetlands of International Importance under the Convention on Wetlands (Ramsar, Iran 1971) in 1983. This region, known as the Pitt Water-Orielton Lagoon Ramsar site covers approximately 3,289 ha. It met the criteria for Ramsar listing: Criteria 2(a) because it supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plants and animals, and an appreciable number of individuals of any or more of these species; Criteria 2(b) because it is of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its flora and fauna; Criteria 2(d) because it is of special value for one or more endemic plant or animal species or communities; and Criteria 3(b) because it regularly supports substantial numbers of individuals from particular groups of waterbird, indicative of wetland values, productivity or diversity (DPIWE 2001b). The Pitt Water Nature Reserve of 776 ha is incorporated into the Ramsar site and includes Orielton Lagoon, Barilla Bay, Woody and Barren islands and the northern section of Pitt Water.

The saltmarshes in Pitt Water Estuary are considered to be one of the most important areas of this type in Tasmania. This reserve contains all but one of the poorly reserved species of saltmarsh in Tasmania and several threatened species (e.g. *Sclerostegia arbuscula* (Barilla bush). The dominant species near the mouth of the Coal River, Samphire Island and Duck Hole Rivulet are *Sarcocornia quinqueflora* (samphire), *Sclerostegia arbuscula* (Barilla bush), and rushes *Juncus krausii, Gahnia filum, Stipa stipoides, Distichlis distichophylla* and *Samolus repens* (DPIWE 2001b). Similar species are found around Barilla Bay, with the exception of *Juncus krausii*, and small areas of *Salicornia blackiana* are present.

6.2.2 Conservation status

Pitt Water Estuary was classified by Edgar *et al*. (1999) to be of low conservation significance, largely because of the relatively high human population density in the catchment and associated activities. Edgar *et al*. (1999) classified 111 estuaries in Tasmania, firstly by grouping estuaries according to their physical, geomorphological and hydrological attributes, and then validating or amending them according to biological attributes. Finally, estuaries in each group were ranked according to the current level of anthropogenic impact. This classification, however, did not include an assessment of avian fauna or wetland plant communities; only flora and fauna that are fully aquatic or regularly immersed on high tide were included. Pitt Water Estuary was also classified as severely modified in the Land and Water Audit based on the information provided in Edgar *et al*. (1999).

6.2.3 *Aquatic habitats.*

Habitats in an estuary are important in determining the physical functioning of the estuary and the flora and fauna that occur there. Seagrasses, in particular, play an important role in nutrient cycling as well as providing food and shelter for a wide diversity of species. They are highly productive and are a major source of primary production in estuaries and coastal waters. In other southern Australian estuaries, seagrass meadows have been found to provide important habitats for invertebrate fauna and juvenile fish and they are used as nursery areas by several commercially important fishes. Seagrasses also play an important role in stabilising sediments and reducing turbidity (Howard and Edgar 1994).

Pitt Water originally contained large beds of seagrass which declined significantly in the late 1900s. However, recent surveys indicate an increase in seagrass coverage in Pitt Water (see below).

Intertidal sand and mud flats of estuaries are also important feeding grounds for both resident and migratory birds. In southern Australian estuaries the macrofauna is generally dominated by polychaetes, crustaceans and molluscs, which are important items in the diet of a variety of water birds (Hodgkin 1994). At Pitt Water, intertidal flats exposed during low tides are important feeding areas for waders including sandpipers, stints, curlews, knots, oystercatchers. Other species, such as terns, feed by diving for fish.

Extensive intertidal areas are also important nursery habitats and feeding grounds for juvenile and adult fish, including commercially valuable species of flounder. A survey by Crawford (1984) over 15 months in 1980-82 of juvenile flounder at four sites in lower Pitt Water found that juvenile greenback flounder, *Rhombosolea tapirina*, and to a lesser extent, the long-snouted flounder, *Ammotretis rostratus*, were very abundant in shallow water (<1 m) in most months of the year. A maximum density of 69 juvenile *R. tapirina* per 100 m^2 was recorded.

6.2.4 *Commercial assets*

Pitt Water estuary is of high commercial value because of the shellfish aquaculture production in the estuary. The introduced Pacific oyster *Crassostrea gigas*, was first introduced into Tasmania at Pitt Water in the late 1940's - early 1950's and has been cultured commercially in upper Pitt Water since the early 1980's. There are seven shellfish leases covering an area of 108.9 ha in upper Pitt Water at Barilla Bay and near Shark Point. Production of oysters from Pitt Water has generally ranged between 5 and 7 million per annum over the last decade (Table 6.2). The current value of the industry is estimated to be $2.5 million, and has averaged in excess of $2 million per annum since 1988. In 1999, 42 permanent and casual staff were employed on the farms in Pitt Water and the indirect economic impact was estimated at 3-4 persons employed per 10 ha of fully developed lease area (DPIWE 2001a).

Limited commercial fishing occurs in the estuary and the total catch is confidential because less than five fishers operate in this area (data supplied by DPIWE to National Land and Water Audit on Australian estuaries). It is, however, an important nursery area for school shark *Galcorhinus australia* and gummy shark *Mustelus antarcticus*, and has been declared a protected shark nursery area. A study of shark nursery areas by the CSIRO found that Pitt Water has the highest and most consistent annual catch rate of school shark pups in Tasmania. Over the summer months the population of school shark pups in Upper Pitt Water was estimated to be 1100 (Stevens and West 1997). However, the number of shark pups in all Tasmanian nursery areas has declined substantially since the 1940's, but it is not known how much of this decline is due to overfishing of adults or a reduction in quality and quantity of nursery grounds.

6.2.5 Recreational assets

The recreational value of Pitt Water is rated as high because it is a relatively sheltered and picturesque expanse of shallow water only 15 minutes drive from the centre of Hobart. This area is widely used for a variety of water sports including swimming, wind surfing, water skiing, canoeing, recreational fishing and pleasure boating. Regular recreational fishing, in particular for flounder and flathead, occurs in the estuary, especially south of the causeway and from the first causeway bridge. Boating, using both sailing and power boats, is also a popular activity. The Midway Point Yacht Club is located north of the causeway.

Table 6.2. Annual production of oysters from Pitt Water.

Year	Total to market (millions)
1985	2.25
1986	2.13
1987	2.90
1988	7.40
1989	8.73
1990	6.38
1991	6.72
1992	5.04
1993	5.83
1994	6.60
1995	4.98
1996	4.90
1997	5.33
1998	4.85
1999	5.24
2000	5.40
2001	7.35

Bird watching is a popular recreational pursuit in the Pitt Water Ramsar site because of the presence of a relatively high diversity of migratory and resident bird species.

6.2.6 Scenic/tourism assets

Because of its close proximity to Hobart airport, its location on a major tourist route to the Tasman Peninsula and the relatively large expanse of estuarine waters on both sides of the two causeways, the scenic value is rated as high. The Pitt Water Ramsar site also has potential for further ecotourism development. This area is increasingly being recognised as an important bird watching site in Australia and is attracting interstate and overseas visitors. Bird watching facilities for the general public are also being developed in the region to protect the more sensitive habitats.

In recent public consultation over whether oyster farming should be permitted in lower Pitt Water, the Sorell Council strongly opposed this development, stating that they wanted to keep this area relatively pristine for recreational activities and for tourism ventures that are currently being developed.

6.2.7 International Agreements over the region

The saltmarsh and intertidal sand and mud flats of Pitt Water are important feeding areas for migratory birds from as far away as the Artic tundra. It is one of the major summer feeding grounds in Tasmania and is the southern most major summer feeding area in Australia. Twenty six bird species, predominantly waders, which occur within Pitt Water-Orielton Lagoon are listed on the Japan/Australia Migratory Bird Agreement (JAMBA) and twenty seven species have been listed on the China/Australia Migratory Bird Agreement (CAMBA). Australia thus has international obligations to ensure the protection of listed migratory bird species and their habitats.

6.2.8 Pitt Water Protected Environmental Values (PEVs)

PEV’s are in the process of being set for the Pitt Water Estuary (Table 6.3). However, these PEV’s differ slightly from those listed for Pitt Water in the DPIWE Proposed Environment Management Goals for Tasmanian Surface Waters, South-East Coast Catchments Public Discussion Paper 2001. In particular, the latter document includes primary contact as a value. These differences need to be clarified (pers. comm. Shane Hogue, Water Management Objectives Officer, DPIWE).

These PEVs are clearly linked to flow-related issues. They identify the community requirements for high water quality for recreational activities and aesthetic values. Protection and maintenance of the aquatic environment by providing water of appropriate quality and quantity is also identified as being important. Maintenance of several communities, such as seagrasses and wetlands listed under the Ramsar convention, and populations of the endangered viviparous seastar are highlighted as being of special significance. However, the PEVs recognise that this is a modified system that supports shellfish aquaculture and fishing.

Table 6.3. PEV's for Pitt Water Nature Reserve (from DPIWE 2001b).

Upper Pitt Water *A Protection of Aquatic Ecosystems:* modified ecosystem from which edible fish, crustacea, and shellfish are harvested and having regard to the values for which the site is listed under the Ramsar Convention. *B Recreational Water Quality and Aesthetics* secondary contact (for activities which are permitted under the management plan or regulations); aesthetics That is, as a minimum, the water quality of surface waters in Upper Pitt Water shall be managed to provide water of a physical and chemical nature which will support a healthy, but modified estuarine aquatic ecosystem from which edible finfish, crustacea, and shellfish may be harvested; and which will, in particular, protect existing seagrass beds; and which will enable people to safely engage in recreational activities such as boating and fishing in aesthetically pleasing waters.
Orielton Lagoon *A Protection of Aquatic Ecosystems:* modified ecosystem from which edible fish, crustacea, and shellfish are not harvested and having regard to the values for which the site is listed under the Ramsar Convention. *B Recreational Water Quality and Aesthetics* secondary contact (for activities which are permitted under the management plan or regulations); aesthetics That is, as a minimum, the water quality of surface waters in Orielton Lagoon shall be managed to provide water of a physical and chemical nature which will support a healthy, but modified estuarine aquatic ecosystem from which edible finfish, crustacea, and shellfish may not be harvested; and which will, in particular, support populations of the seastar *Patiriella vivipara*; and which will enable people to safely engage in recreational activities such as boating and fishing in aesthetically pleasing waters.
Barilla Bay *A Protection of Aquatic Ecosystems:* Modified ecosystem from which edible fish, crustacea, and shellfish are harvested and having regard to the values for which the site is listed under the Ramsar Convention. *B Recreational Water Quality and Aesthetics* secondary contact (for activities which are permitted under the management plan or regulations); aesthetics. That is, as a minimum, the water quality of surface waters in Barilla Bay shall be managed to provide water of a physical and chemical nature which will support a healthy, but modified estuarine aquatic ecosystem from which edible finfish, crustacea, and shellfish may be harvested; and which will, in particular, protect existing seagrass beds; and which will enable people to safely engage in recreational activities such as boating and fishing in aesthetically pleasing waters.

7. MAIN ENVIRONMENTAL OBJECTIVES LINKED TO FLOW REGIME

7.1 Coal River

The Coal River is significantly degraded due to a number of historical and ongoing influences. Only part of this is due to changes in the flow regime however. While it is degraded, opportunities for maintaining a viable riverine environment and ecosystem still exist, and rehabilitation activities such as willow removal, are likely to have significant localised effects within the lower Coal.

A key problem for setting objectives and linking them to the flow regime is the degree to which the existing pattern of flows can be changed. The lower Coal is seen as an integral part of irrigation water management in the valley, and any substantial changes to the pattern of delivery of flows will have serious implications for security of supply and the economics of primary production in the valley as a whole. This necessitates a trade-off between desired environmental outcomes and irrigation uses. The list of community values identified for the Coal illustrates a recognition of the utility of the Coal for irrigation combined with a desire to maintain aquatic environmental, fishery and aesthetic values.

In essence, immediate environmental objectives for the Coal must be tied to the recognition of its modified condition. Significant restoration or rehabilitation of the Coal's riverine environment will not be feasible by manipulating flows alone and will require an integrated approach to management of catchment land and water use, catchment and riparian vegetation, dam water quality and releases, and fish passage. No vision of significant restoration or rehabilitation of the natural features of the Coal River and catchment have been articulated by the community to date. In the absence of such a vision and integrated management, the main focus for environmental flows must be on maintenance of existing values and prevention of further degradation.

The primary environmental objectives for the lower Coal that are linked to the flow regime we can identify are therefore as follows:

- Maintenance of instream habitat quantity and quality;

- Maintenance and/or rehabilitation of existing native and recreational fish populations;
- Maintenance of the existing platypus population;
- Maintenance of existing macroinvertebrate communities;
- Maintenance of existing macrophyte communities;
- Maintenance of riparian vegetation;
- Maintenance of pool habitats and their water quality;
- Maintain low risk of major erosional events during large floods;
- Maintenance and/or improvement of water quality;
- Maintenance of aesthetic values of the river, especially in the vicinity of the Richmond Bridge.

7.2 Pitt Water

Because Pitt Water is at the bottom end of the catchment ('the end of the ditch'), many of the environmental problems that occur in the Coal River catchment are likely to be strongly reflected in the estuary. This is especially the case in Upper Pitt Water, which is little influenced by inflow of oceanic waters, and hence relatively less buffered from changing flow regime in the Coal River. Thus the effects of activities occurring inland and relatively remote from estuaries, such as land clearing and concomitant changes in sediment movements and extraction of substantial quantities of water for irrigation, should be assessed not only for localised impact, but also for impact that can occur downstream and far removed from the original activity. Hence environmental objectives related to flow regime for the Pitt Water region are also strongly linked to the flow regime for the Coal River.

Environmental objectives that we have identified for Pitt Water estuary in relation to flows that are required to maintain, and where necessary improve, the water quality and dynamics of sediment movement in Pitt Water Estuary are as follows:

- Maintenance of the flora and fauna of the wetlands in the Pitt Water - Orielton Lagoon Ramsar site, which are on the list of Wetlands of International Importance.

- Protection of the threatened flora and fauna of the region that have been listed under the Tasmanian Threatened Species Protection Act 1995.Maintenance of the aquatic habitats and natural biodiversity of Pitt Water estuary, especially the seagrass beds and associated flora and fauna
- Maintenance, and preferably increase, the production of oysters from upper Pitt Water.
- Maintenance of commercial fishing and shark nursery grounds.
- Maintenance of water quality such that the general public can continue to safely participate in and enjoy recreational activities in Pitt Water.
- Maintenance of the natural aesthetic values and ecotourism potential in the estuary.

8. KEY FLOW PROCESSES NEEDED TO MEET OBJECTIVES

8.1 Coal River

Two main flow elements are required to construct an environmental flow regime that will achieve the objectives identified for the Coal River – a seasonal pattern of minimum flows (‘baseflows’) and a minimum high/flood flow sequence. Both of these should largely mimic the existing flow pattern, but recognising that:

- baseflows in summer are higher than natural due to irrigation delivery;
- baseflows in winter-spring are much lower than natural due to the absence of releases from Craigbourne Dam, though this is partially offset by lower catchment tributary inputs for the reaches in the vicinity of Richmond;
- some increase in the frequency of smaller flow pulses is desirable to maintain pool habitats and reduce their salinity under low flows;
- some regular higher flow events are needed to restrict the degree of channel contraction due to sediment accumulation.

8.1.1 Minimum Flows

A series of minimum flows is required which maintain instream habitats throughout the year. These minimum flows should vary seasonally, by month, to mimic the historical pattern of baseflows over the last 10 or so years, but should be set so as to minimise the risk of further habitat loss.

8.1.2 High/flood Flows

To achieve the environmental objectives for the Coal River and the estuary we would also recommend a pattern of high/flood flow events, with each event designed to perform specific ecosystem functions. We recommend four major types of high flow/ flood events, each with a different role, and all of which are considered essential for the maintenance of the riverine/estuarine ecosystem (Table 8.1). Not all of these may be appropriate to the Coal River, with its highly modified channel and sediment history, however. The risks and benefits of these high flow/flood events for the Coal/Pitt Water system will be explored in the next section of this report.

Table 8.1. Key potential environmental roles of four high flows/flood event types in the Coal River and Pitt Water estuary.

Flood Type	Ecosystem Role
Median flood	Channel maintenance, sediment transport to estuary.
Annual flood	Channel maintenance, sediment and LWD transport within river, sediment and nutrient transport to estuary, estuarine flushing.
Triggers	Downstream fish migration: native fish. Upstream fish migration: native fish, trout. Coarse organic material transport, estuarine mixing and nutrient delivery.
Freshes	Maintain riparian vegetation; flushing of algae and fine organic material; aquatic and riparian plant dispersal and germination. Periodic pool-pool connection and salt flushing.

For this project, *median floods* are those floods with a 1 in 2 year average return interval, while annual floods are the average annual maximum floods. Both of these flood sizes play key roles in maintaining channel form, primarily though sediment transport, as well as key processes like meander migration. *Annual floods* also play a role in the transport of large woody debris (LWD). *'Trigger' high flows* are flows considered essential for triggering key biological events. These flows are required in these rivers to initiate downstream migration of native fish for spawning (in autumn-early winter) and brown trout, as well as upstream migration of native fish juveniles (e.g. 'whitebait', which includes the juvenile forms of galaxiid fish and other species, and elvers – typically in spring). Trigger flows are also likely to play key short term roles in estuarine hydrodynamics, as well as in the transport of coarse organic material (CPOM) in river channels. Smaller, more regular *'freshes'* are required for several purposes, most noteably maintenance of riparian and instream vegetation, local transport of fine particulate organic matter (FPOM) and flushing of algal biofilms, and in the Coal, saline pool waters.

8.2 Pitt Water

8.2.1 Conceptual model of Pitt Water Estuary

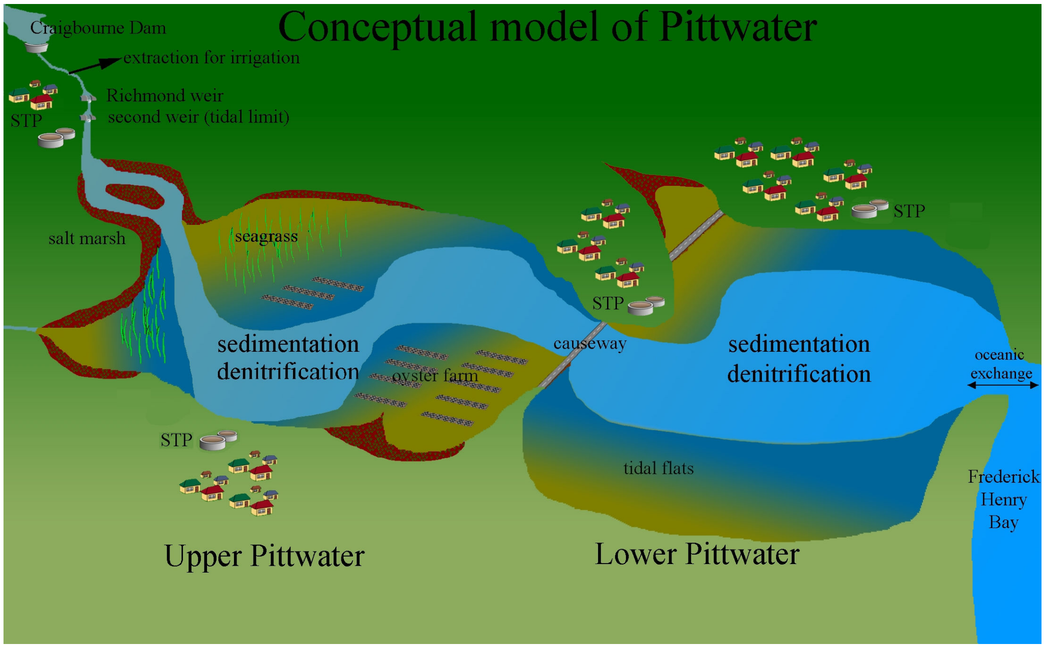
A conceptual model of Pitt Water estuary (Figure 8.1) highlights the important features and processes in the estuary. As mentioned above, this estuary has been markedly changed from its natural condition before human settlement in the region. A combination of increased sediment load into waterways of the catchment due to widespread land clearance and agricultural activities and reduced flows due to extraction for irrigation has led to a progressive increase in siltation and narrowing of the Coal River and sediment deposition in upper Pitt Water. The upper reaches of the estuary are now much narrower and shallower than in the early 1800's.

This conceptual model of Pitt Water is very similar to the standardised model of wave dominated estuaries in Australia developed by GeoScience Australia (Heap *et al*. 2001). They describe wave-dominated estuaries as being characterised by a central basin, with nutrients and fine-grained particles being trapped year round, a barrier/back-barrier that restricts flushing and promotes stratification, and naturally low turbidity. However, significant turbidity can occur when the central basin is relatively shallow and internal wind waves are able to resuspend fine sediment. This appears to be the dominant situation in upper Pitt Water, both under pre-development and current conditions.

Wave dominated estuaries are also characterised by a high risk of eutrophication, a high risk of habitat loss due to sedimentation and a risk of increased turbidity, and this is the likely situation for Pitt Water.

Nitrogen cycling in Pitt Water also appears to follow the model developed by Heap *et al*. (2001) for wave-dominated estuaries. In this model, nitrogen enters the estuarine system from point and non-point sources, with biological uptake of dissolved inorganic nitrogen (DIN) in the central basin area when residence times are sufficiently high. This is the likely scenario for Pitt Water, especially in upper Pitt Water where the turnover rate is lower. Decomposition of organic matter within the sediment produces DIN, and denitrification results in much of the N being released to the atmosphere. Pitt Water differs from this standard conceptual nitrogen model in that the largest quantities of N enter via oceanic waters, and not from riverine inputs or re-cycling.

(a)



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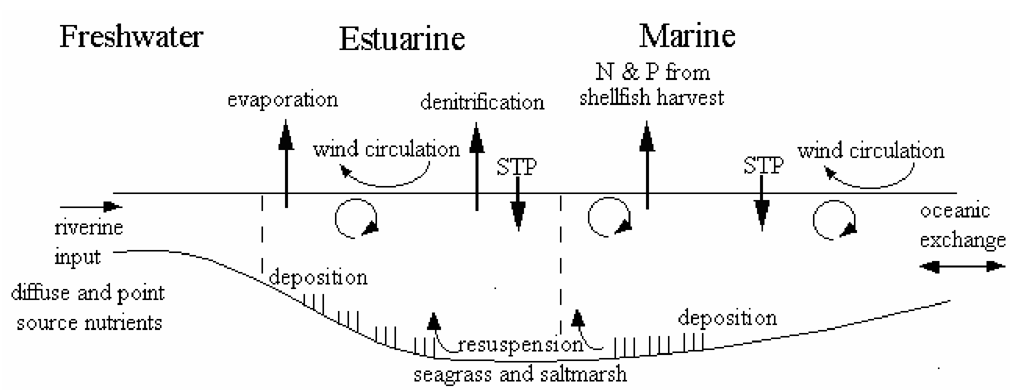


Figure 8.1. Conceptual model of Pitt Water estuary.

The Pitt Water Orielton Lagoon Ramsar Site Management Plan 2002 suggests that heavy sedimentation may be one of the biggest problems for Pitt Water. Areas of soft sediment in sections of the Coal river below Richmond have been estimated at from 50 cm to over 1 m (DPIWE 2001b, Mitchell 2000 pers. comm.). The depth of these deposits indicate that sedimentation of the region has been occurring for some time, and most likely since the early 1900's when extensive clearing for agriculture occurred in the catchment. However, the effects of the Craigbourne Dam and resultant altered freshwater flow regimes on Pitt Water estuary are not clear. Reduced flows would reduce the amount of sediments being transported into the estuary and they would generally be finer muds than previously. However, fewer major floods would also result in reduced flushing and dispersal of deposited sediments.

Because flood intensity and frequencies are now lower since the construction of Craigbourne Dam, fine sediments tend to accumulate just above the weirs. To avoid these sediments being washed into Pitt Water during large floods, they should be periodically removed from the weirs and disposed of at an appropriate waste disposal site.

8.2.2 Modelling the impact of Riverine flows on Pitt Water Estuary.

Flows into the estuary

In its current state much of Pitt Water estuary is strongly dominated by tidal marine exchange. Flow into Pitt Water from marine sources averages approximately 433 cumec, while flow over the Richmond weir averages 0.6 cumec. Marine flows are greatest at high tide when the volume of water moving past a single point is highest (Figure 8.1).

Tidal flow over a 30 minute period (the time between tide height measurements) was calculated as:

$$((H_0-D)*30 +|(H_{30}-H_0-2D)|*30/2)*V*W + W*D*V*30$$

where V is the average velocity (m/min), W is width of the estuary (m), D is the minimum depth (m), H_0 is the first measurement in a 30 minute period and H_{30} is the tide height after 30 minutes. These rough calculations reflect only the gross volumes of water passing Lewisham. More accurate estimations would require more accurate estimates of *V*, *W* and *D*.

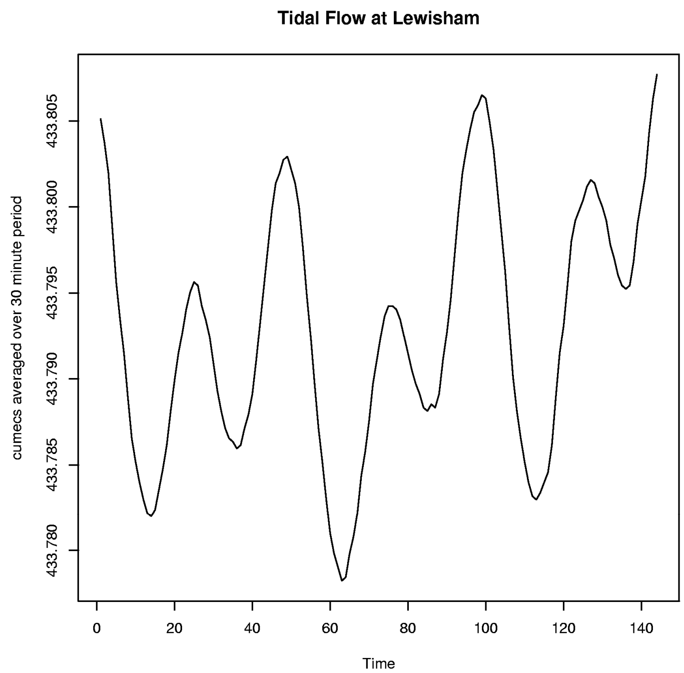


Figure 8.2. Tidal flow across Pitt Water estuary at Lewisham (m3/s) over a 3 day period (144 samples taken).

It is difficult to define the movement of the tidal prism and salt wedge up the estuary, although tidal influence can be seen below the Richmond weir. Flows from the Coal river are sufficiently low that salinity remains consistently high. During the period salinity was monitored (27-8-91 to 4-10-94), recorded levels at Shark Point in the upper estuary were never less than 31.5 ppt, although no major floods occurred during this time.

The estuary could not be modelled using standard numerical techniques. The data collected from 27-8-91 to 4-10-94 were input into simple inverse estuarine transport models. However, there were insufficient data from the upper estuary at lower salinities to form a gradient of salinity from marine to freshwater, and in some cases salinity was greater in the upper estuary than in the lower estuary due to low flows and evaporative loss. Limited data on water flows at the weirs at Richmond also made investigations of relationships between flow, rainfall and salinity levels extremely difficult. Consequently, the exchanges predicted by the simple inverse models made little sense. As an alternative, the effect of flow on salinity and water quality was examined at Shark Point in upper Pitt Water.

Effect of freshwater flow at Shark Point

Flow from Richmond weir was compared to salinity values recorded from 27-8-91 to 4-10-94. The flow had the greatest correlation with salinity two days after flows had been recorded at Richmond Weir (Figure 8.3). Flow across the Richmond Weir was weakly negatively related to salinity at Shark Point:

$$\text{Salinity (ppt)} = -3.28 * \text{Flow(cumec)} + 35.25; r^2=0.112$$

Given the relatively high contribution of incoming tidal flows compared to freshwater flows, it is not surprising that flow from Richmond Weir has weakly correlated with salinity, even in the mid-upper estuary.

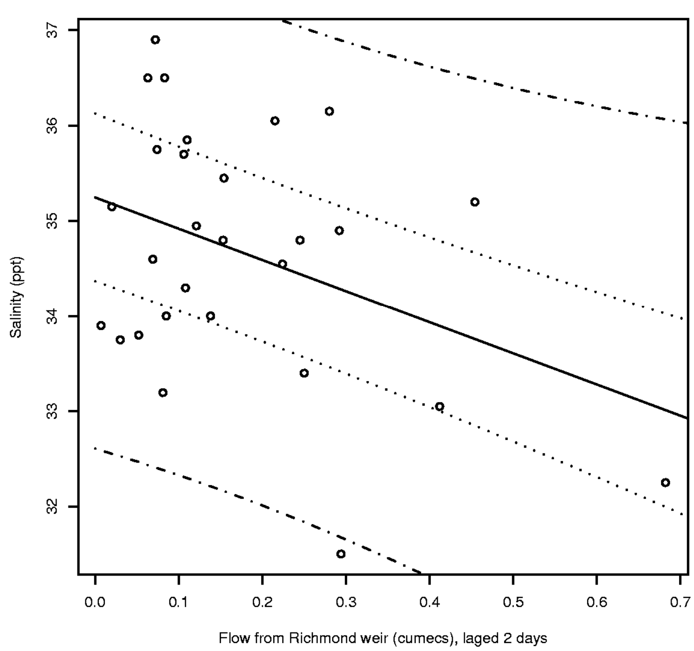


Figure 8.3. The relationship between salinity and flow at Richmond weir. The solid line represents the predicted relationship from a

linear model with 50% and 95% prediction confidence intervals (dotted and dashed lines respectively).

Phosphates and nitrates

Phosphates (DRP) in the water were strongly correlated to salinity at Shark Point. Levels of PO_4 increased with salinity (Figure 8.4).

$$PO_4\ (\mu g/l) = 1.32 * \text{Salinity(ppt)} - 36.4;\ r^2=0.369$$

When salinity was high phosphates were imported into the estuary. Conversely when salinity was depressed through freshwater input phosphate levels were lower. It appears that the relative contribution of phosphates from freshwater sources is lower than the contribution from marine sources. The nutrient budget also indicates that at average low flows, most phosphates will come from marine sources.

However, an analysis of the relationship between nitrogen and other environmental variables found no consistent relationship between nitrogen and flow, salinity, phosphates or chlorophyll a.

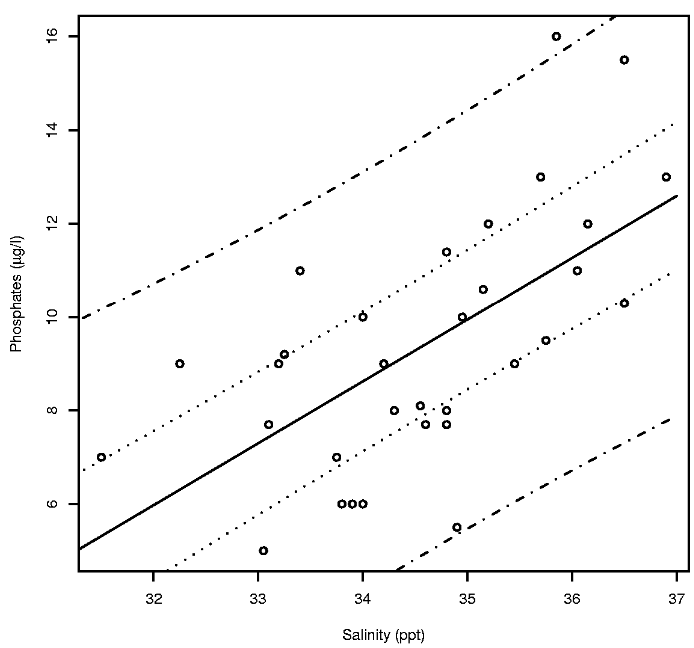


Figure 8.4. The relationship between salinity (ppt) and phosphate levels. The solid line represents the predicted relationship from a linear

model with 50% and 95% prediction confidence intervals (dotted and dashed lines respectively).

Chlorophyll a

Levels of chlorophyll *a*, a surrogate for biomass of phytoplankton in the estuary, were weakly related to phosphate concentrations (Figure 8.5).

$$\text{Chlorophyll a } (\mu g/l) = PO_4(\mu g/l)*0.225 + 1.054;\ r^2=0.102$$

The variability in this relationship can be explained in part by the dependence on nitrogen by phytoplankton for growth. It should be noted that high chlorophyll *a* levels are not possible without a combination of high phosphates and nitrate loads, and they are also dependent on environmental conditions with in the estuary. It is possible that primary production and sedimentary deposition of nutrients is absorbing the considerable inputs from marine, freshwater and anthropogenic sources, and that nitrogen is being lost from the system by denitrification in shallow waters. The magnitude of denitrification could not determined in this study. Given the frequent non-linear responses of systems to changes, it is possible that small increases in the current nutrient budgets could lead to major shifts in the condition of Pitt Water estuary. It is not possible to determine the size and direction of these changes without further study.

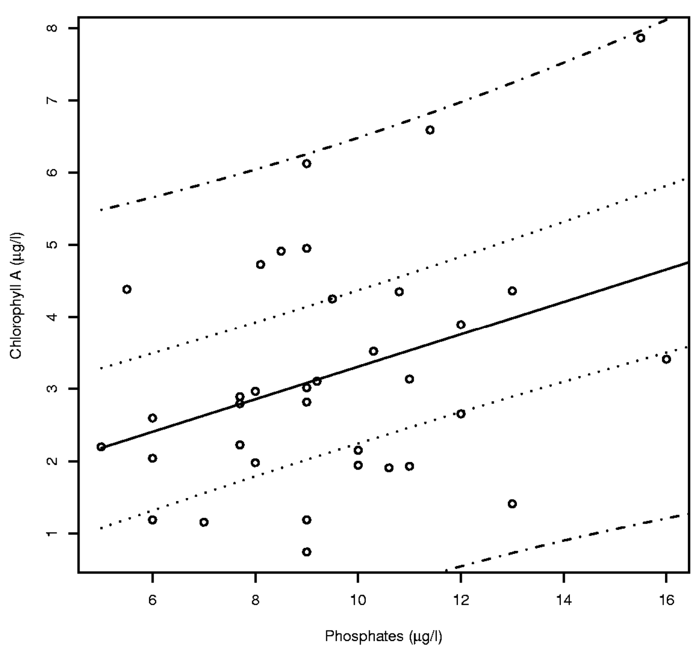


Figure 8.5. The relationship between phosphates and chlorophyll A levels. The solid line represents the predicted relationship from a linear model with 50% and 95% prediction confidence intervals (dotted and dashed lines respectively).

Silicon

Input of silicon from freshwater into Pitt Water estuary, measured as concentrations at Shark Point, was strongly correlated with flow when the flow rate exceeded 0.13 cumec (Figure 8.6). When flow is low, silicates are present at low background levels (approximately 200 µg/l). However, as flow increases, silicon levels increase logarithmically (Silicon = 250.12*log(flow) + 517.48; r^2= 0.96).

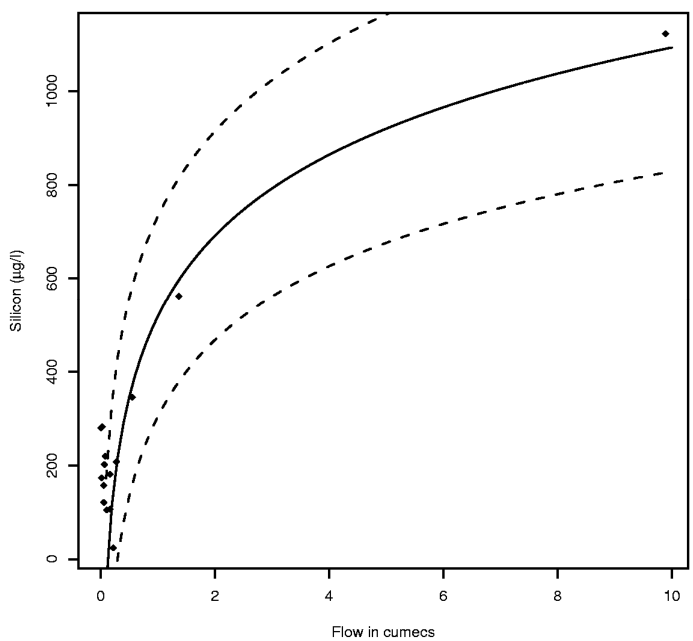


Figure 8.6. The relationship between flow across Richmond weir in cumec and silicon levels recorded at Shark point. Dashed lines show the 95% prediction intervals.

The effect of changes in flow on salinity

Freshwater flow into Pitt Water estuary has changed considerably over the 16 years since the construction of Craigbourne Dam and weirs at Richmond. As is apparent from historical and modelled natural flow records (Figure 1.3), high flow events in the Coal River have decreased in frequency, and low flows have been raised during summer-autumn. This has had an effect on estuarine salinity. Figure 8.7a shows the predicted salinity levels under modelled natural flow conditions. It is apparent that even under natural flow conditions, salinity is usually at or close to marine levels (i.e. 76% of the year).

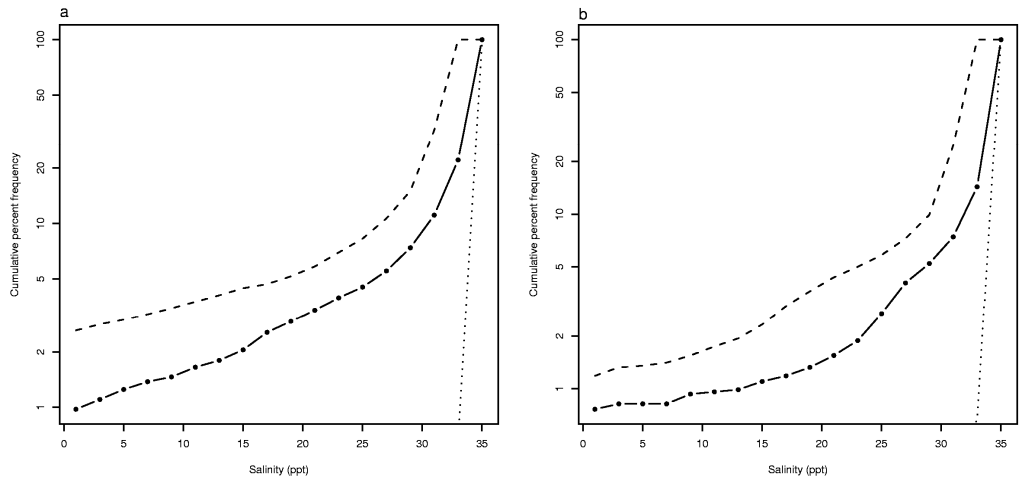


Figure 8.7 The cumulative percentage frequency of salinity derived from: (a) the estimated natural flows (see Figure 1.3, Natural) in the Coal River (i.e. without dams or weirs) and (b) the recent historical flows (see Figure 1.3, Actual) across Richmond weir for the same period (1987-2002). Salinity values are predicted using these flow rates with the relationship between salinity and flow shown in Figure 8.3. Dashed and dotted lines represent upper and lower 95% prediction intervals.

The current flow regime at Richmond weir produces slightly different results (Figure 8.7b). Consistent low flow in the estuary means that salinity values are still usually at marine levels (84% of the year). However, the estuary at Shark Point is more likely, under current flow conditions, to have high marine salinity (8% of the year, approximately 1 month; Figure 8.8). Likewise, salinity in the range of 27 to 33 ppt is less likely, by approximately 1 month. It is in this intermediate range of salinity values that the impact of flow regulation is most apparent. The frequency of lower salinity levels (i.e. < 27 ppt) has remained relatively unchanged.

This change in intermediate salinity values may be of importance to the healthy functioning of the estuary. Salinity levels in the range of 27 to 33 ppt provide small intermediate level disturbances to the estuary. Intermediate disturbance levels have been suggested as beneficial to many marine systems and may promote increased biodiversity and prevent any one species or guild of species from attaining dominance within their trophic level. Additionally, these salinity values lie within the range that maximises the reproductive potential of the viviparous starfish (discussed below).

This change in salinity in the upper reaches of the estuary is reflected in the increased abundance of the introduced Pacific oyster with distance up the estuary. Although oyster farming has been occurring in upper Pitt Water since 1984, beds of wild oysters have only become established in the narrow stretch between Lands End and Richmond in the last few years and a large oyster bed has formed near the bend in the river to the north west of Samphire Island. This species is known to prefer more saline estuarine conditions, generally above 24‰.

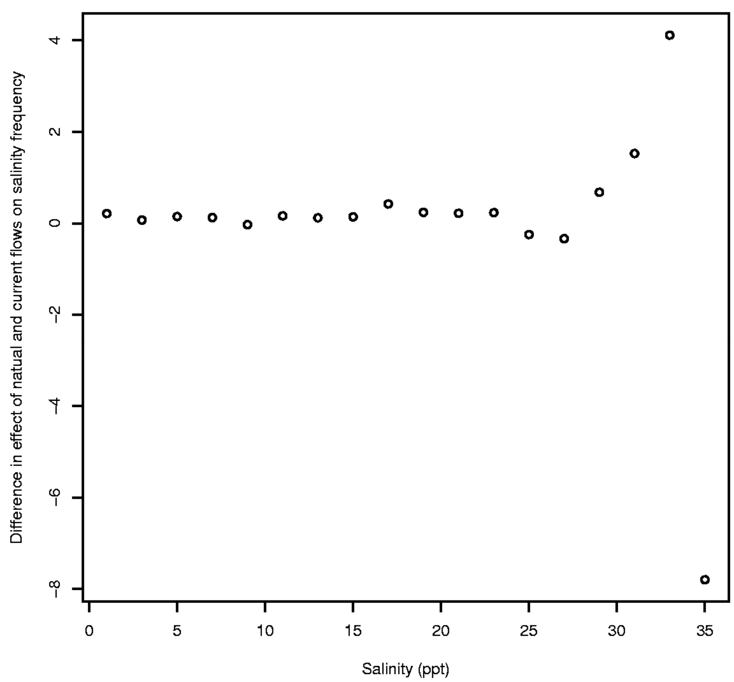


Figure 8.8 The difference in the frequency of salinity levels between "natural" (Figure 8.7a) and actual (Figure 8.7b) flow regimes. The difference reflects the impact of dams and weirs on flow and consequently salinity.

8.2.3 Impacts of the changed flow regime on Pitt Water

The regulated flow regime into Pitt Water may have impacted on estuarine ecosystems by:

- Reduction in water quality because of reduced turnover rate;
- Reduced input of organic matter and essential nutrients for primary production;

- Increased deposition of fine sediments, especially in the upper estuary, which can affect aquatic habitats;
- Extended penetration of saline waters into the upper estuary, which can affect the distribution and abundance of sensitive floral and faunal species;
- Extended duration of marine conditions in the middle and lower reaches of the estuary, allowing the displacement of estuarine species by marine biota;
- Reduced frequency of flushing of fine sediments and organic matter, especially from the upper estuary;
- Reduced connectivity between the estuarine and freshwater systems;
- Altered salinity/chemical cues for migrating fish.

We now address the effects that these changes to ecological processes as a result of modified flows can have on the environmental assets of Pitt Water using the available, albeit limited, information.

8.2.3.1 Aquatic habitats - seagrasses

Changes in the distribution of seagrass and saltmarsh habitats and shallow unvegetated banks in upper Pitt Water between 1977 and 2001 were assessed through an examination of aerial photographs. Photograph selection was based on calm water surfaces, suitable sun glint and camera angle conditions, and were sourced from DPIWE. The photographs from April 1977 were at a scale of 1:30,000, while those from April 2001 were at a scale of 1:24,000.

Many factors influence the quality of photographs required for mapping, including water (turbidity) and atmospheric (cloud cover, sun angle) conditions, tidal height, film type (black and white or colour), choice of filter and height, and cover of filamentous algae. In addition, both the rectification and digitisation can impact on the quality of the results, particularly when using historical photographs to reconstruct seagrass distribution. Often the outer (deeper) boundary of beds are difficult to define and can result in seagrass being mapped in depths where it does not occur. In addition, the shallower areas often have a cover of filamentous algae which are difficult to separate from seagrasses.

Current habitat distributions and bathymetry were estimated through extensive ground-truthing using an echosounder and digital video surveys in June 2002, as described by Jordan *et al*. (2001). Habitats were classified as seagrass, patchy seagrass, sparse seagrass, sand, silty/sand, silt or shell. When depths were too shallow to map, all points shoreward of the position were defined as that habitat and clipped to the coastline.

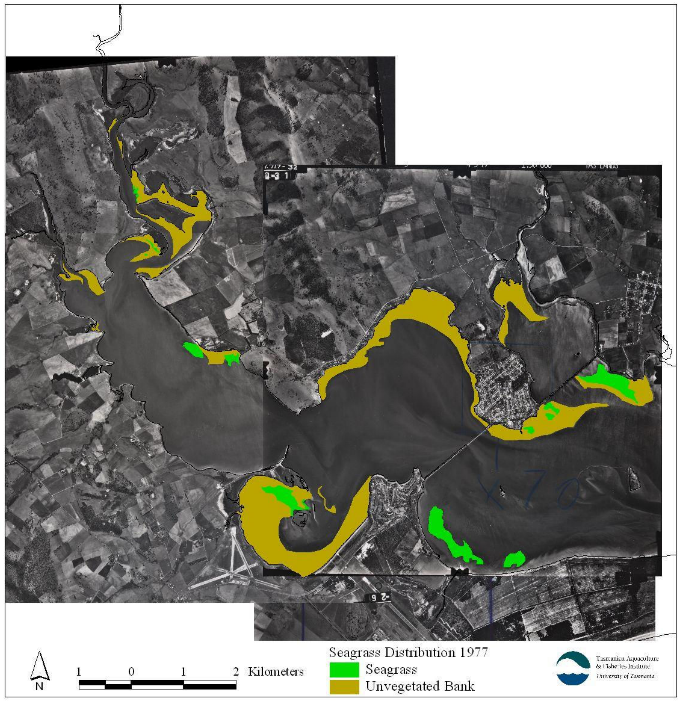
The distribution of habitats in 1977 to a large extent reflects the quality of the aerial photographs (which were black and white) and therefore the ability to discriminate habitat boundaries. There is evidence of seagrass beds north of Shark Point, northern Barilla Bay and the Samphire Island area that had a combined area of around 0.25 km^2 (Figure 8.9). Shallow unvegetated banks were also evident along the northern and southern shorelines south of Shark Point and in the vicinity of Samphire Island. However, poor photograph quality results in a large central area that is impossible to classify.

The distribution of seagrass beds in upper Pitt Water was also mapped in the late 1940s, 1969 and 1990 through the analysis of aerial photographs (Rees 1993). The area of upper Pitt Water was estimated to have around 2.27 km^2 of seagrass in the 1969, representing a decrease of approximately 55% from the late 1940s. Much of the seagrass loss is in intertidal areas and was therefore primarily composed of *Zostera muelleri*. As Rees (1993) relied on aerial photography to map the seagrass distribution, there is likely to be a considerable amount of error in defining the boundaries of beds. For example, much of the area identified to have seagrass in the 1940s is in the channel and may have been incorrectly categorised. A further loss of 2.05 km^2 (or around 90%) of seagrass was estimated to have occurred between 1969 and 1990, leaving an area of only 0.22 km^2 (Rees 1993).

Anecdotal evidence of seagrass distributions in Pitt Water indicates that much of this loss occurred in the early 1980s as the beds in the mid 1970s were described as 'healthy' and increasing in size in intertidal areas (Prestedge 1996).

In 2001, seagrass beds were identified south and west of Horatio Point and northern Barilla that had a combined area of around 0.63 km^2 (see Figure 5.4). Extensive areas of shallow unvegetated banks were also evident throughout upper Pitt Water. It appears that these larger seagrass areas compared to that defined for 1977 most likely reflect better photograph quality rather than the expansion of habitat.

(a)



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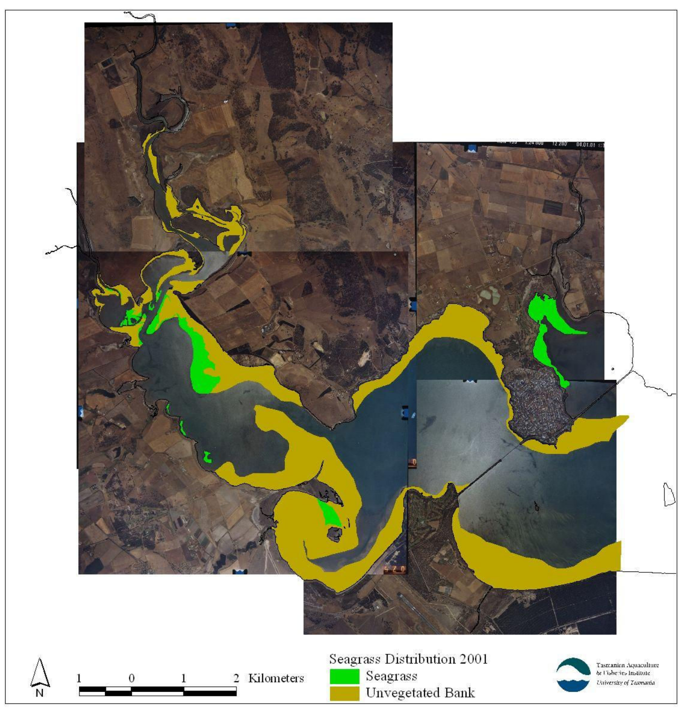


Figure 8.9. Aerial photographs of Pitt Water estuary (a) in 1977 and (b) in 2000.

Comparison of photographs from 1977 and 2001 also shows a loss of seagrass in lower Pitt Water in the shallow bay south of the first causeway. As this is intertidal, the species would have been mainly *Zostera muelleri*. Intertidal beds of this species are now uncommon in Tasmania and a combination of changing environmental conditions and human activities are probably responsible for this loss. Seagrass beds in Orielton Lagoon were not compared because of the major changes that have occurred in this region due to human interference.

Habitat distributions and bathymetry mapped from field surveys of upper Pitt Water in June 2002 represent current distributions with minimal error compared to that generated solely from aerial photographs (Figure 5.4). Extensive seagrass beds were identified on both sides of the main channel south and west of Horatio Point. There were also small sparse patchy beds around 2 km north west of Railway Point. These beds had a combined area of around 0.82 km^2 and were restricted generally to depths <1 m. Seagrass consisted primarily of *Heterozostera tasmanica,* although small amounts of *Zostera muelleri* were present on the inner margins. This estimate is based on surveys conducted during winter and therefore represents distribution during the period of lowest biomass and cover.

There is some evidence of natural variability in the distribution and abundance of seagrass beds, although the extent of these variations is substantially different between species and strongly influenced by depth and exposure, and varies with water column and sediment conditions. Species with low rhizome biomass such as *Zostera* and *Heterozostera* tend to be much more variable in their growth as there are few storage reserves available during periods of low light and nutrient availability. As *Heterozostera* and *Halophila* are the dominant species in eastern and southern Tasmania, it is expected that natural variations (interannual or longer term) are common. This is supported by anecdotal evidence from Pitt Water where significant long-term changes in seagrass area were evident (Prestedge 1996).

The unvegetated habitats in upper Pitt Water are dominated by silty/sand shoreward of approximately the 2 m depth contour and silt within the deeper channel area north of Shark Point and broadly over a deeper basin south of Shark Point. The entrance to upper Pitt Water north of the causeway is dominated by sand and shell habitat reflecting the faster current speeds in that area. The upper reaches north of the Coal River junction consist primarily of bedrock covered by a layer of silt.

While there is evidence of significance loss of seagrass in upper Pitt Water over the past 25 years, problems with the interpretation of aerial photographs make any accurate assessment very difficult. However, given the seagrass area of 0.82 km^2 from field surveys in 2002, there has either been a significant increase in seagrass or the 1990 estimate of 0.22 km^2 by Rees (1993) was an underestimate.

It is also difficult to definitively assess the impacts of increased nutrients and turbidity on seagrass in upper Pitt Water due to the frequent natural variations in this habitat, the lack of historical monitoring data, the lack of suitable controls for comparison; and a poor understanding of the fate and fluxes of nutrients in the region.

Thus it is not possible to make any definitive statements on whether the changing freshwater flow regime has affected the sea grass coverage in Pitt Water estuary. Nevertheless, increased sedimentation has occurred in the upper reaches of the estuary, and this, in combination with increased nutrient input into the estuary from STPs and agricultural activities, has most likely affected sea grass viability. In Western Port, Victoria, where the dominant species are similar to those in Pitt Water, major loss of sea grass has occurred, especially of *Zostera muelleri* in intertidal areas. The principal mechanism for this decline is thought to be fine muds settling on seagrass leaves and reducing the light levels, although other factors are implicated (Shepherd *et al* 1989). In upper Pitt Water, sea grass coverage appears to have increased in the 1990s, and this may be due to improved treatment of sewage and reduced sediment input into the estuary (although interpretation of poor quality aerial photographs could be significant).

8.2.3.2 Natural biodiversity

Estuarine fauna are a specialist group of euryhaline or specially adapted organisms that thrive in the constantly changing estuarine salinity environment. If this environment changes to a more stable marine system, then typically dominant marine organisms will displace the estuarine fauna (Barnes and Hughes 1988). Unfortunately little baseline data exist on faunal and floral species composition and abundance of aquatic estuarine species in Pitt Water. Without this information is not possible to accurately assess whether changes have occurred due to the altered hydrological regime in the estuary. However, studies in other locations have clearly shown that such changes can occur as a result of changed flow regimes.

8.2.3.3 Conservation - wetlands (RAMSAR)

Saltmarshes in Pitt Water, similar to others around Australia, differ to salt marshes in the northern hemisphere in that they rarely contain drainage creeks or saltpans (Morrisey 1995). They are also often inundated only during extreme spring tides, or when flooding occurs. Very few studies have been conducted on the productivity of saltmarshes in Australia, and it is not known what proportion of the production is exported to adjacent habitats or in which state of decomposition (fresh plant material, detritus, dissolved nutrients etc.) (Morrisey 1995). Results from a study of various plant communities in Botany Bay suggested that saltmarshes contributed only about 6% of primary production to the Bay. The salt marsh at Railway Point in Pitt Water was observed by Wong et al. (1993) to have a small submergent area and much larger emergent area. They observed that zonation of salt marsh fauna was largely determined by salinity gradients, degree of inundation and the nature of the substrate. Most of the species collected are thought to occur over a broad range of soil salinities, organic content and moisture content.

We investigated changes in the Pitt Water salt marsh area by comparing marsh area shown in aerial photographs from 1977 with areas mapped in 2000 by DPIWE TasVeg 2000. Figure 8.10 shows the aerial photographs from 1977 with the outline of saltmarsh areas mapped in 2000 overlain in red. Other than a small area of saltmarsh on the northern side of upper Pitt Water having changed to farming land, there is very little difference in saltmarsh area between the two years. This indicates that the saltmarsh beds are relatively stable. However, species composition was not assessed so we do not know if any changes have occurred in species zonation patterns.

However, the long term importance of flood events in the maintenance of saltmarshes should not be underestimated. Saltmarshes often alternate between periods of

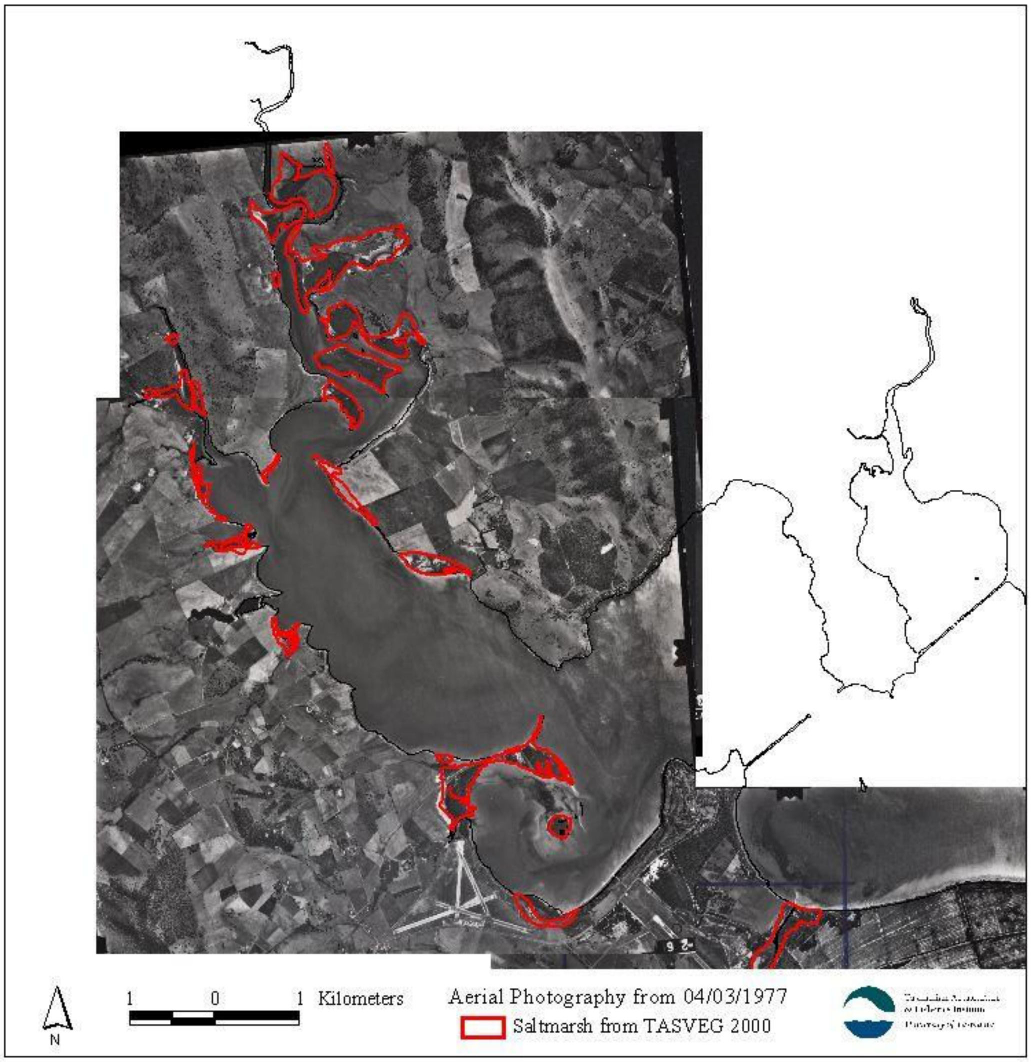


Figure 8.10. Aerial photograph of Pitt Water estuary in 1977. The areas outlined in red are the saltmarsh areas mapped by TasVeg (2000) in 2000.

sediment accumulation and sediment erosion, and it is the overall balance that determines patterns and rates of development of saltmarshes. Occasional major events, such as large floods, can be very important in determining long term development of saltmarshes. For example, in Chesapeake Bay on the east coast of the USA, 50% of all sediment deposited on the saltmarshes between 1905 and 1975 occurred as a result of two major floods (Morrisey, 1995). Thus the area of saltmarsh in Pitt Water could change quickly under extraordinary environmental conditions.

8.2.3.4 Conservation - threatened flora and fauna

Of the rare and endangered fauna listed under the Threatened Species Protection Act 1995, only the endemic viviparous sea star *Patiriella vivipara* is possibly directly affected by the altered freshwater flow regime in Pitt Water estuary. Prestedge (2000) observed the behaviour, survival, and reproduction of *P. vivipara* under experimental conditions with salinity ranging from 15 to 50 ‰. Although the behaviour and survival of his animals was similar between 25 and 35 ‰, reproduction was clearly higher at 30 ‰ (total births from 1978-1981 was 19 at 25 ‰, 81 at 30 ‰ and 45 at 35‰). Prestedge (1998) also found that although *P. vivipara* breeds throughout the year, the main reproductive period is in spring and summer. These results are only preliminary, but do suggest that reduced intensity and frequency of freshwater flows could have a marked impact on the reproduction and survival of this species in the area where it is most abundant.

Changes in sediment type as a consequence of deposition or erosion, can influence the benthic invertebrate community structure and hence food species available for birds feeding, particularly within the exposed intertidal flats of the estuary. Invertebrate species preferred by waders are annelids, crustaceans, and molluscs, with species targeted dependent on the bill shape of the birds that utilise these areas. Birds feeding on the exposed sand/mud flat areas in Lower Pitt Water have been observed to now spend a greater amount of time searching for food and covering greater areas than formally noted (Geoff Prestedge pers. comm.). However, no detailed studies have been conducted on the benthic invertebrate fauna of Pitt Water or of the feeding requirements of migratory birds. It is thus not known whether changes have occurred over time.

8.2.3.5 Commercial fish and shellfish production

Shellfish farmers in the region have strongly argued for years that the growth and condition of their oysters depends on the flow of freshwater into upper Pitt Water. This confirms general observations noted in many countries where oysters are farmed commercially, that Pacific oysters, although tolerant of wide ranging salinities, grow best under estuarine-marine conditions of 25-30 ppt. Freshwater, especially during floods, brings increased nutrients into Pitt Water which stimulate production of phytoplankton and hence increased food for oysters. Under poor growing conditions the oysters take much longer to reach market size, increasing from 12 - 18 months to 2-3 years to reach the same size. The oysters are also much more difficult to condition, i.e. to reach the degree of 'fatness' required for top quality oysters.

However, oyster farming developed in Pitt Water at much the same time as the Craigbourne Dam was built. It is thus very difficult to show that the change in flow into Pitt Water has affected oyster production. Although annual production of oysters has varied over the years, farm management methods have also changed as farmers adapted their growing methods according to the environmental conditions. This has included some farmers only growing their oysters to about 50 mm in length and ongrowing them to market size in another location because the oysters were taking too long to reach market condition in Pitt Water. However, no consistent records of oyster growth rates are available for comparison between years. Nevertheless, the high production figures for 2001 are accredited to the high rainfall and freshwater flow into Pitt Water in spring and early summer of 2001. A much higher number of oysters than normal reached market condition earlier in 2001 than previously and in time for peak sales during the summer holiday period.

Based on experience elsewhere, there is a high probability that flood events also affect the species composition of the phytoplankton. This is related to the availability of nutrients and silicates in particular. Silicates are primarily of terrestrial origin and are at much higher concentrations in fresh than marine waters. They are essential for the formation of diatoms and in areas of high silicate concentrations diatoms generally dominate over dinoflagellate microalgae. Diatoms are generally a more nutritious food source for oysters than dinoflagellates and thus increase oyster growth rates. A survey by Hallegraeff and Tyler (1987) around the oyster farms in Upper Pitt Water in 1985 - 86 just before the Craigbourne Dam was operational, found that the phytoplankton was dominated by diatoms and large dinoflagellates were never abundant. The stomachs of fresh oysters also contained mainly diatom cells.

In recent times it has been recognised that limitation of silicon can drive a shift in phytoplankton assemblage from diatoms to dinoflagellates, or in some case cyanobacterial blooms, which can have major repercussions on estuarine ecosystems.

This can occur under conditions of increased N and P availability but reducing Si, with N and P more able to be rapidly recycled than Si (Officer and Ryther 1980). Freshwater flows are the major source of silicon inputs to an estuary, and this has been shown to be the case for Pitt Water by Mitchell (2001). Thus, periodic floods into Pitt Water are important to maintain silicate concentrations and hence the natural phytoplankton species composition, and to reduce the likelihood of noxious algal blooms.

The importance of maintaining silicon input into an estuary via freshwater flows was emphasised in a detailed study of the Guadiana estuary in south-western Iberia by Rocha *et al*. (2002). In this estuary where 75% of the catchment has been regulated by dams, Rocha *et al*. (2002) found that diatoms bloomed in early spring after high winter loads of N and P. However, silicate levels were depleted during this early diatom bloom and were not replaced because of the low flows. This resulted in successive blooms of chlorophytes and cyanobacteria and concomitant deterioration in water quality.

8.2.3.6 Recreation and tourism

Although Pitt Water estuary is considered to be markedly different from its original pristine state, it is still a very picturesque area, and upper and lower Pitt Water are important regions of the estuary for recreation and tourism. Upper Pitt Water is visible to tourists flying in and leaving from Hobart airport, and tourists to the Tasman Peninsula drive across the causeways, viewing both upper and lower Pitt Water. Tourism is predicted to expand in this region and the Sorell Council has recently been strongly opposed to oyster farming expanding into lower Pitt Water because of the tourism potential of the region.

The important flow issue in relation to recreation and tourism is maintenance of water quality and aquatic habitats. Prestedge (1996) in the first State of the Environment Report for Tasmania documents the general decline in fish abundance in Pitt Water from his personal observations over 40 years. He believes this is related to the disappearance of sea grass beds in the area, which have been affected by high nutrient loads from sewage treatment plants. This has resulted in a decline in invertebrate food eaten by fish, and nursery habitat for juvenile fish.

A study of the ecology of flounder by Crawford (1984) in Pitt Water and other sites in SE Tasmania found that the flounder larvae preferred fully saline conditions; however, juveniles metamorphosed for 2-7 weeks showed a very strong preference for almost freshwater (salinity range 0-3 ‰), when given a choice of salinity from 33 - 0‰ under experimental conditions. Greenback flounder juveniles also showed a preference for fine sands, whereas the long-snouted flounder were dispersed over fine to coarse sand substrates. This ontogenetic change in salinity preference from saline to freshwater conditions, in conjunction with change in depth preference of larvae, is obviously important in drawing flounder juveniles into shallow productive estuarine nursery grounds.

Freshwater outflow thus plays an important role in attracting flounder and most likely other juvenile finfish and elasmobranchs, such as school and gummy shark and whitebait, into Pitt Water estuary. The research by Crawford (1984) was conducted prior to the establishment of Craigbourne dam and the change in freshwater flows into Pitt Water. It would be interesting to repeat her surveys to see whether the abundance and distribution of juvenile flounder in Pitt Water has altered. She also investigated the diet of juvenile flounder in lower Pitt Water, and similarly, information on diets of flounder some twenty years later would help determine whether the invertebrate fauna has changed in Pitt Water.

8.2.4 Summary of Pitt Water responses to flow changes

The changes in key environmental values in Pitt Water are due to combinations of changes in sediment and nutrient delivery to the estuary as well as in the flow regime, and other local impacts from development. It is difficult, especially in the absence of reliable data on many parameters, to clearly define changes which have been driven by changes in flow. We believe the evidence to date, coupled with the broader understanding of how this kind of estuarine system responds to river flows, suggest that the change in flow regime has resulted in changes in the frequency, magnitude and timing of flood events and of silicate delivery to the estuary.

The relative dominance of a 'marine state' in the estuary has been enhanced by the reduction in winter baseflows, coupled with the reduction in flood flows. A number of key values in the estuary are sensitive to salinity and would require salinity fluctuations to maintain viable populations. While we have no specific data supporting changes induced by a shift toward a more marine condition, we believe that restoration of a degree of freshwater input to allow partial restoration of a fluctuating salinity conditions would be of significant benefit in maintaining key biodiversity values in Pitt Water and especially in the upper estuary and Ramsar area.

Nutrient delivery from the Coal catchment to the estuary has probably increased (see Table 4.3), but this is likely to have been due to land use changes, and may not have influences the overall nutrient budget of Pitt Water substantially, other than in the uppermost sections of upper Pitt Water where marine exchange rates are limited. Much better data are required on water quality in the lower Coal and its relationship with flow, especially flood events. Data on denitrification rates are also needed to assess overall N status.

Substantial changes in sediment dynamics have undoubtedly occurred (see Table 4.1), with obvious sediment accumulation in the upper estuary. The combination of greater sediment yield due to catchment development, coupled with the storage effect of Craigbourne Dam on upper-catchment sediment delivery makes elucidation of current trends difficult, and specific data are required to evaluate this issue and its importance with regard to estuarine, and more specifically saltmarsh, morphology. Internal sediment (N and P) loadings into the estuarine ecosystem under conditions of low flow are unknown and need to be assessed.

9. ENVIRONMENTAL FLOW REGIME – COAL RIVER

9.1 Environmental flow assessment - Minimum environment flows

The minimum environment flow analysis assessment, was conducted in the manner described by Davies and Humphries (1995) and Davies et al. (2001). An assessment was conducted of:

- habitat-flow relationships for the dominant instream faunal taxa;
- wetted area-flow relationships to assess bed exposure and risk of channel invasion by willows.

No attempt has been made to develop relationships between geomorphological processes and river flows, due to limited data and resources.

Risk of habitat loss at a series of nominal discharges was assessed relative to a reference flow value for each month and compared with criteria believed to represent various levels of risk. Details are as follows.

9.1.1 Hydraulic data

Staff from DPIWE Water Resource Assessment Branch selected two representative reaches for hydraulic assessment of instream habitat in the lower Coal. Detailed hydraulic data was collected from the two survey sites located at Daisy Banks (Grid refs of downstream transect = 5269575N, 536040E) and at Mt Bains (Grid refs of downstream transect = 5286800N, 533310E).

11 transects were established at the Daisy Banks site, covering a total of 253 m of stream length. 10 transects were established at the Mt Bains site, covering a total of 479 m stream length. The transects were sited to represent the dominant mesohabitats in the reach, as follows (Table 9.1).

Each transect was established with a steel 'head' peg on the bank as a local datum from which all water surface elevations (stage) were measured. Each site was rated on at three occasions, starting in November 2001, with stage and discharge measured over a range of flows. Problems were experienced with obtaining reliable gaugings due to low flows at Daisy Banks. These were overcome by conducting additional gaugings to check water levels. No high flow gaugings were possible due to sustained

Table 9.1. Mesohabitats covered by transects at two representative reaches in the Coal River. Transect 0 is at the downstream end of each study reach.

Daisy Banks		Mt Bains	
Transect Number	Mesohabitat	Transect Number	Mesohabitat
0	pool	0	riffle
1	glide	1	glide
2	pool	2	slow glide
3	pool	3	riffle
4	run/glide	4	mod glide
5	riffle	5	riffle
6	run	6	slow pools
7	deep run	7	slow pools
8	run/glide	8	slow pools
9	riffle	9	riffle
10	pool tail		

low flows during the study period and high flow ratings were estimated from Mannings' equations (see below).

At each site, the channel profile was surveyed, and velocities and depths measured at ca. 0.5 - 1 m intervals from the head peg across the full width of the channel. At each interval, substrate composition was recorded (as % of the following grain size classes/types – silt (<1 mm), sand (1 - 4 mm), gravel (4 - 16 mm), pebble (16 - 64 mm), cobble (64 - 256 mm), boulder (>256 mm), bedrock, as well as area of aquatic vegetation.

9.1.2 Habitat-preference curves

Habitat preference data were required for the native fish and macroinvertebrate species observed in the lower Coal, as well as for platypus.

Macroinvertebrates:

Habitat preference data for macroinvertebrates had to be derived from instream sampling. Accordingly, 40 quantitative surber samples were collected, with sampling location stratified to cover a range of depth, substrate and velocities available within each study site. Sampling was accompanied by measurement of depth and substrate composition of the exact sampling location. In addition, mean water column water velocity was measured at each location.

This yielded 20 sets of quantitative macroinvertebrate-habitat data for each site, . All macroinvertebrate samples were sorted completely and identified to family and species level. A total of 19,247 and 43,086 individual macroinvertebrates were obtained from the Daisy Banks and Mt Bains sample sets, respectively. The data set was used to derive two sets of habitat preference curves, one for each site, as follows.

The abundance data for all macroinvertebrates encountered in each sample were entered into an Excel spreadsheet and screened. Only taxa which complied with minimal requirements for developing habitat preference curves (taxa occurring in > 6 samples) were analysed further. Habitat preference curves were then prepared from this set of screened taxa abundance data, as well as substrate, velocity and depth data for each sample, in a standard manner (Bovee 1986, Stalnaker *et al.* 1995, Humphries *et al.* 1996).

Habitat preference curves were generated for the Daisy Banks site for 42 taxa, which included mayflies, caddis, chironomids, simuliids, molluscs, bugs, amphipods, Paratya shrimp, and phreatoicids: *Austrocercoides* sp., *Nousia* sp. (total), *Atalophlebia* sp. (total), *Tasmanocoenis* sp. (total), *Atriplectides dubius*, *Lingora aurata*, *Ecnomus* sp., *Anisocentropus latifascia*, *Marilia fusca*, *Taschorema* complex (total), *Cheumatopsyche* sp.(total), *Oxyethira mienica*, *Hellyethira* sp. (total), *Notalina* sp. (total), *Triplectides ciuskus ciuskus*, *Oecetis* sp., Chironominae, Orthocladiinae, Tanypodoninae, *Austrosimulium furiosum*, *Simsonia* sp. (total), *Austrolimnius* sp. (larvae), *Kingolus* sp. (total), *Austrolimnius* sp. (ad), *Kingolus* sp. (ad), *Necterosoma* sp. (larv), *Sclerocyphon secretus* (larv), *Micronecta* sp. (total), *Pisidium casertanum*, Hydrobiidae sp. (total), Planordidae sp. (total), *Paraleptamphopus* sp., *Paracalliope* sp., *Austrogammarus* sp., *Austrochiltonia* sp., *Parataya australiensis*, *Colubotelson* sp., *Heterias* sp., Turbellaria, Oligochaeta, Hydracarina, *Austroaeschna* sp. (total).

Habitat preference curves were generated for the Mt Bains site for 23 taxa, which included mayflies, caddis, chironomids, simuliids, molluscs, amphipods and phreatoicids: *Nousia* sp. (total), *Atalophlebia* sp., *Tasmanocoenis* sp.(total), *Lingora* *aurata*, *Ecnomus* sp. Type 2, *Helicopsyche murrumba*, *Taschorema complex* (total), *Ulmerochorema* sp. (total), *Cheumatopsyche* sp.(total), *Oecetis* sp., Chironominae, Orthocladiinae, Tanypodoninae, *Austrosimulium furiosum*, *Austrosimulium* sp. (pupae.), *Pisidium casertanum*, *Rivisessor gunnii*, *Physa acuta*, *Austrochiltonia australis*, *Colubotelson* sp., Turbellaria, Oligochaeta, Hirudinea sp.

In addition, curves were developed for the total number of taxa and the total abundance of all macroinvertebrates at each site, these latter developed using data for all taxa in each sample set.

Fish and platypus:
Habitat preference data were used from existing sources for platypus (Davies et al. 2000) and for the following native fish species shown to be present within the two catchments: shortfin eel (*Anguilla australis*), common jollytail (*Galaxias maculatus*), and brown trout (*Salmo trutta*). Habitat preference data for fry, juvenile, spawning and adult stages of trout from (Raleigh et al. 1986) were also used, due to the presence of a previously locally important trout fishery.

Aquatic vegetation and snags:
No habitat preference data were available for aquatic macrophytes or snag habitat for the Coal.

9.1.3 Habitat-flow analysis

Habitat-discharge (WUA-Q) curves were developed for all biological variables (macroinvertebrate and fish taxa, macroinvertebrate abundance and number of taxa, platypus) for the two study sites. Hydraulic simulation was conducted over the flow ranges 0 – 0.5 and 0 - 1.01 cumec for the Daisy Banks and Mt Bains sites, respectively, using the RHYHAB simulation package. Dry conditions prevented collection of high flow ratings necessary for simulation to higher discharges. The range of flows for which simulations could be conducted was sufficient, however, to include all monthly reference discharges.

Stage at zero flow (SZF) values were calculated from lowest point in transect for all transects which were riffles and glides (see raw data sheet for transects descriptions). All pool transect SZF's were estimated by using the mean of all maximum depths from the riffle/glide sites (0.5 m) and subtracting from the WSE observed for the full gauging. All sites were assumed to have the same flow (the mean over all transects), as they were all gauged in the one day.

9.1.4 Minimum flow risk analysis

In order to derive a minimum environmental flow regime for both rivers, the risk-assessment approach described by Davies and Humphries (1996) was used. This involved a risk assessment of habitat loss for the key biota, relative to a reference flow for each month of the year.

A 'reference' flow was required against which to assess changes in habitat and hence risks to biota. Two reference flows were explored initially – 'historical' and 'natural'.

'Historical' flow reference: With the aim of maintaining instream habitat under the current irrigation scheme operating conditions, a reference discharge was selected which represented median habitat conditions occurring over the last 15 years. A grand median mean daily flow was calculated for each month derived from the historical flow record supplied by DPIWE, for the period 10/1987 to 5/2002. This seasonal, monthly set of flows was taken as representing the 'typical' historical flow condition (Table 9.2).

'Natural' flow reference: A modeled natural flow record was supplied by DPIWE, for the period 10/1987 to 5/2002. A grand median mean daily 'natural' flow was calculated for each month from that record, to derive a 'natural' reference flow regime. However, this flow regime was so far removed in seasonal pattern and magnitude from the current, or historical, flow pattern (see Figures 1.1 and 1.2), in including the occurrence of cease-to-flow conditions in summer/autumn (Table 9.2), that it was decided not to pursue the minimum flow risk assessment against natural flow further.

Average monthly flows unduly bias reference flows upwards and distort the analysis, therefore the median of mean daily flows were used to assess 'median' reference flows. The grand median monthly flows for Daisy Banks (Richmond) and Mt Bains (downstream Craigbourne) used as the basis for reference flows are shown in Table 9.2.

In addition to using a reference flow describing the 'median' historical flow condition, an assessment of Environmental Flow requirements for dry or drought condition years was conducted. This recognizes the need to provide minimum environmental flows which recognise the natural variability in low flows associated with dry conditions. The 20th percentile of mean daily flows for each month over the same period of record (1987-2002) was used to derive the reference flow regime for dry conditions (Table 9.2). The use of the 20th percentile (as opposed to a smaller percentile) recognises the need to reduce baseflows in response to moderate rather than extreme dry conditions.

Using the approach described by Davies and Humphries (1996), the following analysis was conducted for the two lower Coal sites:

1) Reference flow selection

The 'historical' reference flow was selected for each month (Table 9.2).

2) Habitat change

A series of nominal flows at between 0 and 0.5 or 1.0 cumec intervals were selected for simulation.

The % deviation of habitat availability (WUA) at the nominal flow from the WUA at the reference flow for that month was then calculated using the following formula:

$$\textbf{\%DelHA = 100*(}^{\textbf{WUAQnom}}/_{\textbf{WUAQref}}\textbf{)}$$

where WUAQnom = WUA at the nominal discharge and WUAref = WUA at the reference flow.

This was done for all the biological 'values' listed above, including macroinvertebrates, platypus, and fish.

Separate sets of %DelHA values were calculated for each month.

3) Risk categories

Each value of habitat deviation (%DelHA) was converted to a risk category according to the criteria originally established by Davies and Humphries (1996), as shown in Table 9.3. For this analysis, the risk being assessed is the risk of failure to maintain biota due to loss of habitat availability relative to reference flow conditions. Results for individual macroinvertebrate taxa were kept separate.. The same risk criteria were used for all biological values.

Table 9.2. Median and drought conditions 'historical' reference flows used in the risk analysis for determining minimum environmental flows for the Coal River at two sites. Figures given in cumec (upper) and ML/day (lower). Note presence of zero flows under natural conditions.

	Richmond (Daisy Banks)				Downstream Craigbourne (Mt Bains)			
	Historical		Natural flows		Historical		Natural flows	
Month	Median	Drought	Median	Drought	Median	Drought	Median	Drought
m^3s^{-1}								
Jan	0.18063	0.17917	0.00163	0.00017	0.29189	0.17409	0.00343	0
Feb	0.17928	0.17900	0.00028	0	0.23660	0.14724	0	0
Mar	0.17906	0.17900	0.00006	0	0.18176	0.11129	0	0
Apr	0.17909	0.17900	0.00010	0	0.17498	0.06953	0.00763	0
May	0.18410	0.18244	0.00727	0.00487	0.08561	0.01478	0.01279	0.00493
Jun	0.19003	0.18580	0.01562	0.00969	0.03476	0.01478	0.02483	0.01425
Jul	0.37966	0.21062	0.24719	0.03686	0.01674	0.00485	0.12332	0.03002
Aug	0.48379	0.37660	0.39320	0.24070	0.01663	0.00260	0.20801	0.05121
Sep	0.55836	0.42968	0.47686	0.28619	0.11831	0.01240	0.17067	0.05062
Oct	0.33453	0.27351	0.18775	0.10804	0.23861	0.02819	0.10000	0.02566
Nov	0.31211	0.20330	0.14911	0.02920	0.24881	0.12313	0.03642	0.01308
Dec	0.19192	0.18139	0.01652	0.00299	0.32033	0.20802	0.01005	0
ML/day								
Jan	15.606	15.480	0.140	0.015	25.219	15.042	0.296	0
Feb	15.490	15.466	0.024	0	20.442	12.721	0	0
Mar	15.471	15.466	0.005	0	15.704	9.616	0	0
Apr	15.473	15.466	0.008	0	15.119	6.007	0.660	0
May	15.907	15.763	0.628	0.421	7.397	1.277	1.105	0.426
Jun	16.418	16.053	1.349	0.837	3.003	1.277	2.145	1.231
Jul	32.803	18.197	21.357	3.184	1.446	0.419	10.655	2.594
Aug	41.799	32.538	33.972	20.796	1.437	0.225	17.972	4.425
Sep	48.242	37.124	41.201	24.727	10.222	1.071	14.746	4.373
Oct	28.903	23.631	16.222	9.335	20.615	2.436	8.640	2.217
Nov	26.966	17.565	12.883	2.523	21.497	10.639	3.147	1.131
Dec	16.582	15.672	1.427	0.259	27.676	17.973	0.868	0

Table 9.3. Risk categories for all biological values in the lower Coal River and corresponding values (criteria) for %DelHA i.e. % remaining WUA under nominal flow cf reference flow.

Value	**Risk Category**			
	I	**II**	**III**	**IV**
	Minimal risk or beneficial	**Moderate risk**	**High risk**	**Very high risk**
Habitat for macroinvertebrates, fish and platypus.	> 85% of habitat under reference flow	60 – 85% of habitat under reference flow	30 - 60% of habitat under reference flow	< 30% of habitat under reference flow

4) Overall risks and recommended minimum flows

A final risk assessment for each nominal discharge was conducted by taking the lowest risk score (lowest value of %DelHA across all biological variables) as the overall risk across all flows <u>below</u> the reference flow. This was done for each month of the year.

This is a deliberately conservative approach in order to minimise risk to the instream biota. All biological variables were treated equally in this approach. Trade-off between risk levels for different biological values in the absence of specific management targets favouring particular species/biotic groups is an inherently subjective and semi-arbitrary process and is avoided here. However, plots of %Del HA for the taxa with the lowest %DelHA values were made to illustrate their relative contribution to the overall risk assessment.

The lowest discharge associated with Risk Band I (minimal risk) is generally recommended as the minimum mean daily flow in each month. This recognizes both:

- the desire for no additional environmental risk over and above the existing impacts from current levels of water abstraction and land use ; and
- the recognition that actual flows fall below this level in some years.

However, where the values associated with increasing risk at flows close to the reference flow are not deemed of particularly high value, consideration may be given to recommending flows that fall within Risk Band II (moderate risk). No choice between these is presented in this work, and results for both risk bands are reported. Results for severe or extreme risk (Bands III and IV) are not reported, as they are not considered appropriate for recommendation as minimum environmental flows due to the high risk of negative environmental impacts on the existing instream biota.

9.1.5 Upper limits on minimum environmental flows

The approach described above was also used to develop minimum environmental flow thresholds (or caps) considered to prevent significant harm occurring to the riverine fauna and flora due to sustained high baseflows. Minimum environmental flows are relevant when considering abstractions or flow reductions in river systems. Coal River irrigation management, however, uses the river channel as a means of delivering irrigation flows to downstream users. This raises the issue of what are the maximum rates of flow delivery which can be supported without causing harm to the ecosystem. This recognizes the fact that there are both lower and upper limits to the magnitude of minimum flows within which a river ecosystem can be maintained in a sustainable state.

Upper limits to minimum flows were assessed using the results of the risk analysis described above, and applying the same criteria (in Table 9.3) for assessing deviations in habitat availability at flows above the reference flows for each month. This was only done for median conditions, and for the Craigbourne Dam (Mt Bains) reach, since flow delivery is largely controlled at the Dam.

9.2. Minimum Environmental Flows – Results

9.2.1 Environmental flow assessment - Minimum environmental flow*s*

9.2.1.1 Habitat-discharge relationships

Transect hydraulic and habitat data is shown in Appendix 1, in standard RHYHAB format. Ratings were successfully developed for all sites, although the accuracy of curves at higher flows (>0.5 cumec) could be improved by the addition of high flow gauging data (not possible during the dry conditions prevalent during the study). Problems with gauging accuracy could not be fully resolved within the time available, and higher flows were estimated by extension of low flow stage-discharge curves in RHYHAB. The relative stage at higher flows was cross-checked against the channel profile to assess if results were relatively realistic.

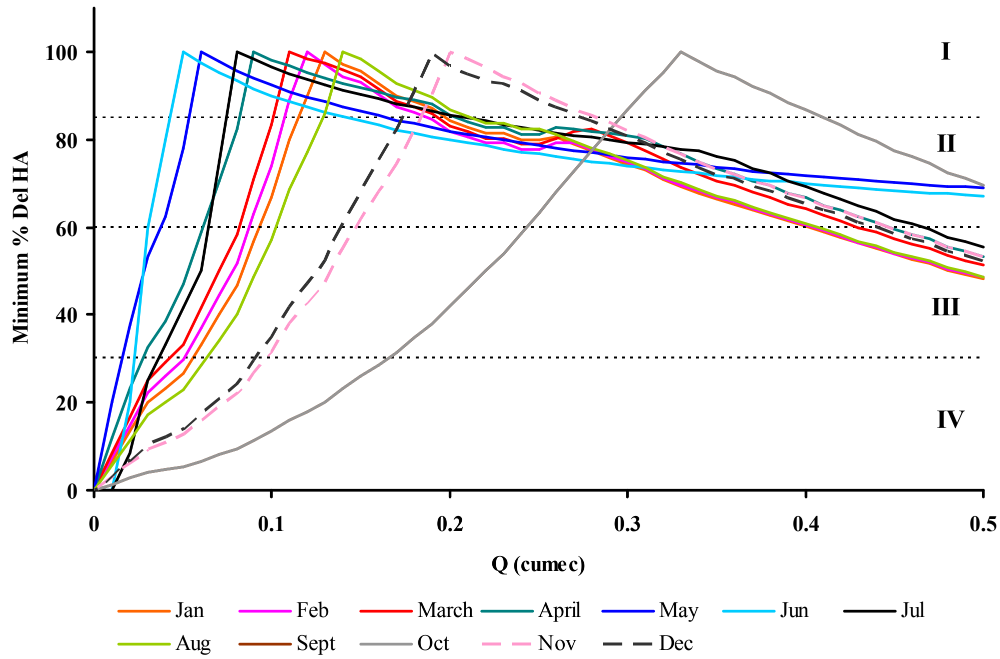
Hydraulic simulations were successfully conducted over the desired flow ranges for all transects at both sites.

9.2.1.2 Risk-assessment

Full risk tables for all taxa have been provided electronically to DPIWE. Figure 9.1 shows plots of the relationships between minimum % Del HA (area of habitat area relative to that available at the reference flow) for each month for the Coal at Daisy Banks. These plots at Mt Bains were similar in form. It can be seen that:

- there is considerable difference between months (seasons) in the degree to which habitat availability is affected by changing flows;
- changes around the reference flow for each month (at which %Del HA is always 100%) are rapid during summer autumn and winter (January to September) compared with spring (October-December)

The sharpness of these curves indicates that there is a strong dependence on flow by a number of taxa. Figure 9.2 shows the detail for one of the curves in Figure 9.1 – for the month of January – for the four most sensitive taxa of the 42 taxa/groups used in the assessment at Daisy Banks. The curve for January under median conditions is mainly developed by following the curve for *Nousia* (a leptophlebiid mayfly) - the taxon with the greatest rate of loss of habitat as flows fall below the reference flow. However, it can be seen that a number of taxa also lose habitat rapidly as flows fall below the reference flow, including the simuliids *Austrosimulium furiosum* and orthoclad chironomids, as shown in Figure 9.2.



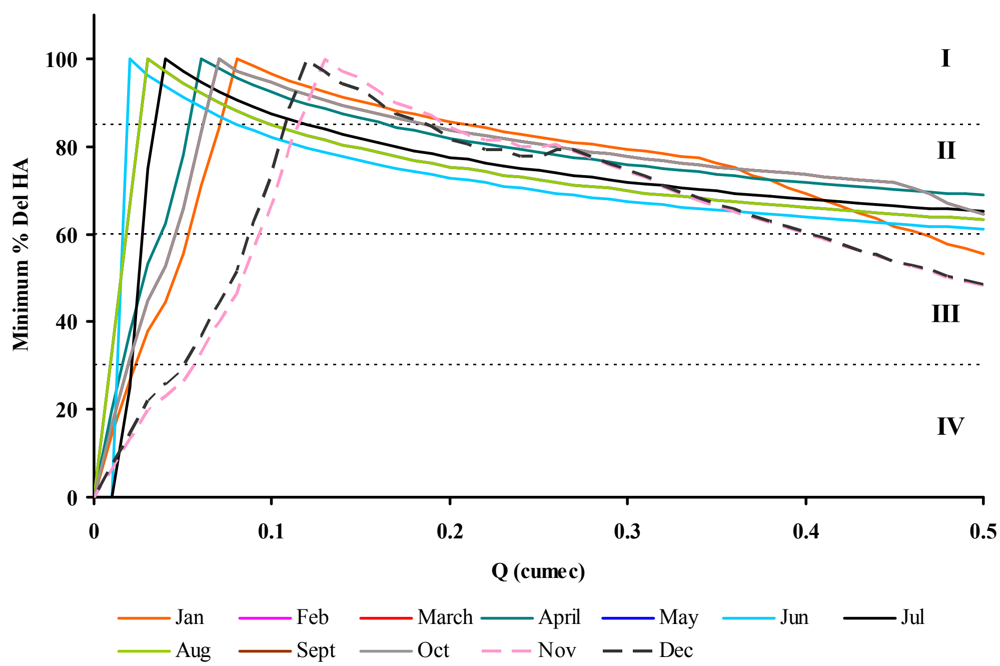


Figure 9.1. Plots of minimum % Del HA vs discharge for each month at Daisy Banks showing peak %Del HA at 100% at each month's reference discharge, and trends on either side of the peak. Plot A = 'normal' (median) conditions (i.e. using the median reference monthly flows), and Plot B = 'drought' (20th percentile)

conditions. I to IV indicate risk bands, with dashed lines at risk band boundaries.

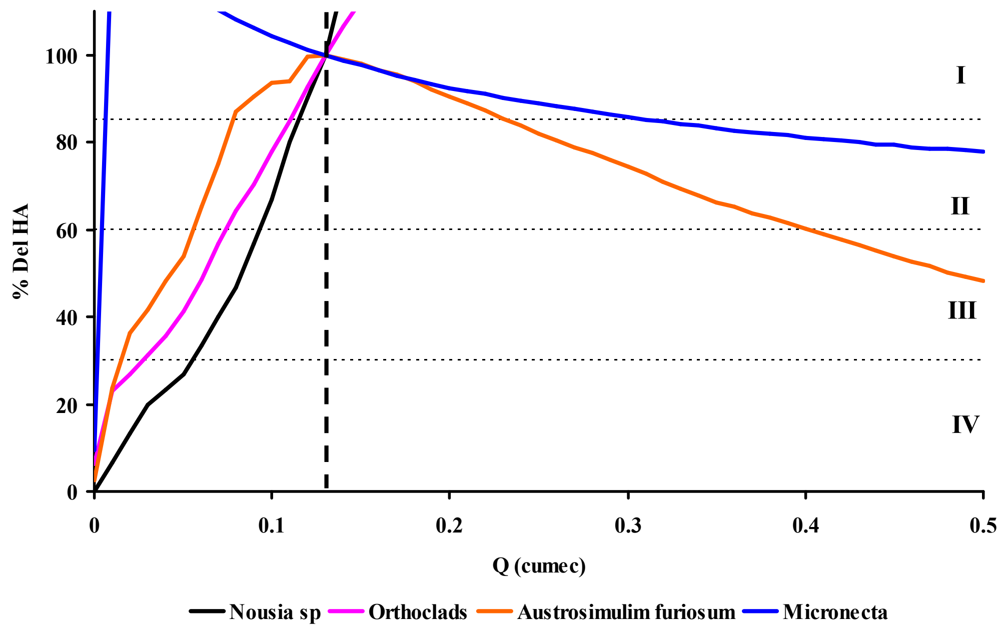


Figure 9.2. Example plots of changes in % Del HA vs discharge for four taxa, showing rapid declines at flows lower than the reference flow (indicated by the vertical dashed line). Data for January, normal conditions, Coal River at daisy Banks. Note that the first three taxa show the most sensitive response in habitat availability at flows lower than the January reference flow, while *A. furiosum* and *Micronecta* spp. have the most sensitive response at flows greater than the reference flow.

9.2.2 Recommended Minimum environmental flows

The lower thresholds for minimum environmental flows estimated from the risk assessment, are shown in Table 9.4 for both study reaches in the lower Coal. These flows are for the lowest margin of the minimal, moderate and significant risk bands (Bands I , II, and III) for each month of the year.

The environmental minimum flow ranges defined by these minimum flow thresholds are also plotted by month in Figure 9.3. Flows falling in Band I, between the reference flow and the lower boundary (the light grey areas in Figure 9.3), satisfy the criteria for minimal environment risk. Flows falling into the next lowest band (Band II) may cause moderate environmental risk, while flows falling lower than this (eg Band III) are deemed to cause significant to high risk to instream biota.

If the desired management goal for minimum environmental flows is minimal environmental risk then the values associated with Band I should be used. If moderate environmental risk is an accepted management goal, then the minimum environmental flows for Band II should be used. Minimum flows within the Band III range may cause significant environmental risk due to loss of instream habitat. Minimal risk (Band I) or moderate risk (Band II) flows are normally recommended in order to minimise risk to the instream environment.

9.2.3 Upper limits (caps) on minimum flows

The upper limits on minimum flows for the lower Coal, derived from the risk analysis, are shown in Table 9.5. Flow delivery downstream in the Coal for irrigation at high levels will increase risk of loss of habitat for instream biota.. The maximum flows shown in Table 9.5 place some restriction on the amount of water that can be delivered downstream from Craigbourne Dam as a steady baseflow without causing environmental impacts, but generally fall at the upper end of recent historical delivery rates.

Table 9.4. Minimum environmental flow thresholds for two levels of risk (minimal, moderate) for the upstream and downstream ends of the lower Coal River, for both 'normal' (median) and drought (20 percentile) conditions. Shown as mean daily flows in ML/day, by month.

	Richmond (Daisy Banks)				Downstream Craigbourne (Mt Bains)			
	Median		Drought		Median		Drought	
Q	Minimal Risk	Moderate Risk	Minimal Risk	Moderate Risk	Minimal Risk	Moderate Risk	Minimal Risk	Moderate Risk
Jan	10.37	8.64	6.48	5.62	24.19	19.87	10.37	12.10
Feb	10.37	8.64	5.62	3.89	17.28	13.82	12.96	9.51
Mar	9.51	7.78	5.19	3.89	14.69	12.96	7.78	6.05
Apr	7.78	6.05	4.75	3.46	14.69	12.96	4.32	3.03
May	4.75	3.46	2.16	1.56	6.91	5.18	3.46	0.86
Jun	3.46	2.59	1.56	1.47	2.65	2.02	3.46	0.86
Jul	6.48	5.62	2.77	2.42	1.33	1.09	0.43	0.30
Aug	11.24	9.51	2.16	1.56	1.33	1.09	0.43	0.30
Sep	25.93	21.61	5.19	4.32	7.00	5.83	3.46	0.86
Oct	19.88	16.42	7.78	6.05	17.28	13.82	3.46	1.73
Nov	15.56	12.96	9.51	8.64	19.01	15.55	7.78	6.05
Dec	15.13	12.10	9.51	8.64	23.33	19.87	16.42	13.83

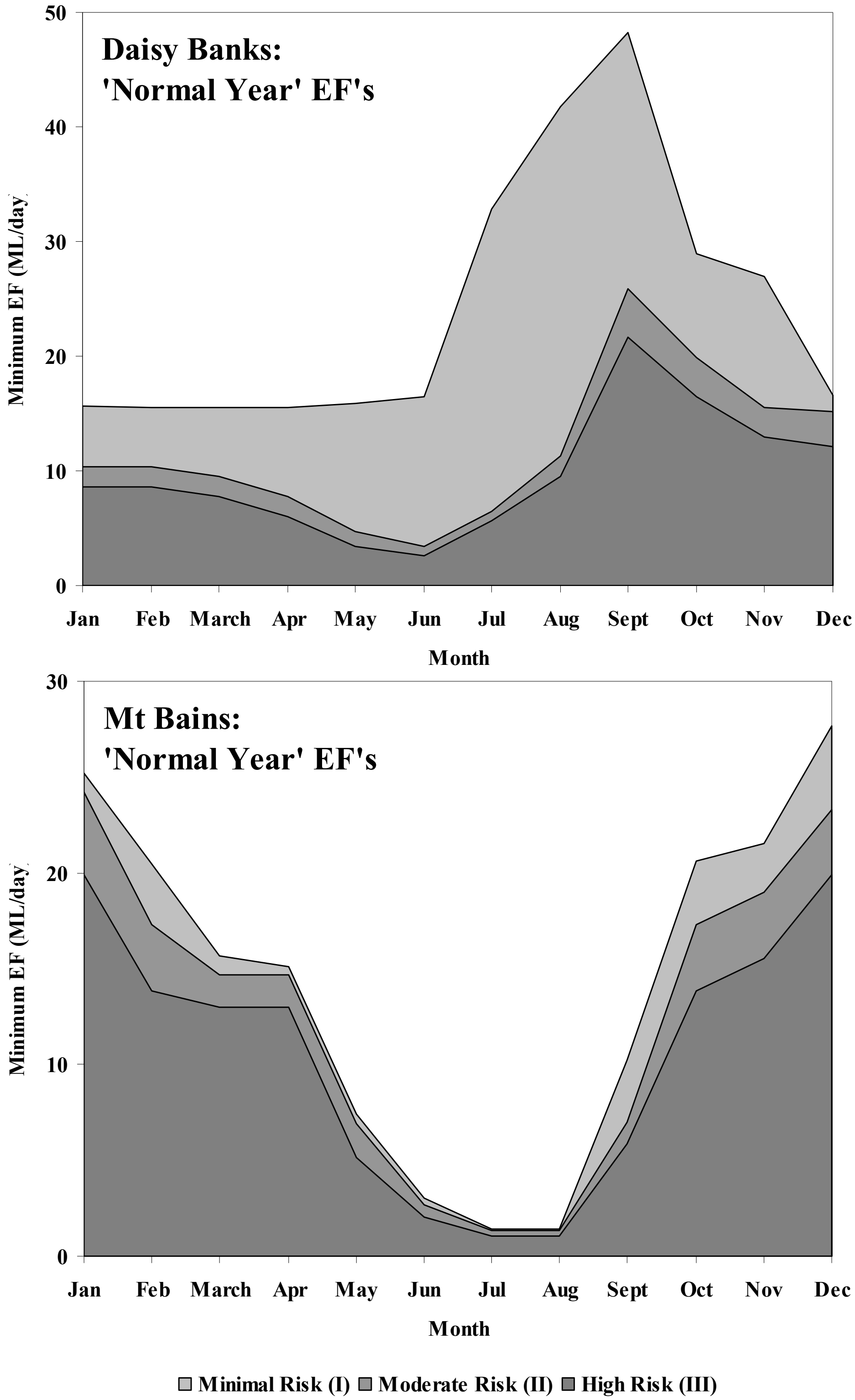


Figure 9.3. Plots of minimum environmental flow ranges for minimal, moderate and high environmental risk under normal (median) conditions for the lower Coal River at two sites.

Table 9.5. Upper limits to minimum flows in the lower Coal River at Craigbourne Dam deemed to present only moderate risk to instream biological values (ML/day mean daily flow for each month).

	Downstream Craigbourne (Mt Bains)	
Q	**Minimal Risk**	**Moderate Risk**
Jan	32.0	38.0
Feb	23.3	27.6
Mar	23.3	27.6
Apr	23.3	27.6
May	25.1	30.2
Jun	35.4	41.5
Jul	42.3	51.0
Aug	42.3	55.3
Sep	23.3	28.5
Oct	23.3	28.5
Nov	25.1	29.4
Dec	31.1	36.3

9.3 Environmental flow assessment – high/flood flows

High flow and flood events are highly significant for maintaining environmental values in rivers and are becoming a key part of defining an environmental flow regime for water management. Flood events largely determine sediment transport within rivers, and interact with landforms to determine the pattern of channel and floodplain features, habitat types and diversity, and substrate characteristics of river channels. Floods are also vital in transporting organic material and as cues for key biological events. It is therefore vital that an environmental flow regime incorporates an appropriate pattern of floods which includes the magnitude, frequency and timing.

Figure 1.3 illustrates the recent historical and natural patterns of flow occurring in the lower Coal. Under pre-regulation conditions, flows were low to very low in summer-autumn. A strong peak in baseflows occurred in winter-spring, accompanied by a series of flood peaks which varied markedly in size. There was also marked interannual variation in flood frequency and magnitude. The main impact of regulation has been to reduce the magnitude and frequency of flood events and to reverse the seasonality of baseflows.

Overall, the assumption has been made in this study that the current channel form is in large part determined by the pattern of flood flows which have occurred over the last few decades to century, in response to natural climatic patterns, land clearing and subsequent damming. We also assume that current habitat and biological features are also in part dictated by the flood sequences that have occurred over the past few to tens of years.

If the primary purpose of the environmental flow regime is simply to maintain current conditions, then a high/flood flow regime which mimics the magnitude, duration and frequency of events in the recent historical record will be sufficient. If the primary purpose is to partially restore/rehabilitate features of the river and Pitt Water which are determined by the high/flood flow regime, then we would recommend inclusion of a series of events which mimics the natural high/flood flow regime. There are strong general philosophical arguments in favour of the latter course, since some measure of rehabilitation from the negative impacts of the high degree of flow regulation may be desirable.

High flows and floods have been classified into four major types in this study, with differing roles, all of which are considered essential for the maintenance of the riverine/estuarine ecosystem (see Section 1.2 and Table 1.1). The incorporation of the larger (*annual* and *median*) flood flows into an environmental flow regime for the lower Coal River is desirable but needs some further investigation to assess both environmental risks and benefits and practicality of delivery.

The absence of regular annual or mid-sized flood events due to flow regulation in the lower Coal, has contributed to the accumulation of material in-channel. While this accumulation has been exacerbated by the relatively dry period since the early 1980's, there is a need to restore intermediate high flow events to reduce the risk of massive adjustment to the channel and sediment erosion when large flood events, which are not significantly controlled by Craigbourne Dam, occur.

Restoration of annual and median floods each of a size sufficient to mobilize sediments in highly contracted channel sections is therefore a desirable component of any future flow regime. This flood may generally approach bankfull at its peak. However, the size of such a flood cannot be accurately determined at this stage due to:

- uncertainties over channel ratings in locations away from gauging stations;
- possible vulnerability of erosion/flooding at specific locations or focus points, which would require further investigation.

Regular provision of near-natural *annual* and/or *median* floods may exacerbate erosion in susceptible channel sections, especially ones undergoing substantial mechanical willow removal. Also, such floods may result in downstream transport of substantial amounts of willow-derived woody debris, a number of significant jams of which have been observed during field surveys. A preliminary field assessment would be required to confirm any possible risks associated with restoration of an annual flood, and such an event should only be introduced on a trial basis at first.

It was not possible to link specific floods/flood patterns with biological cues or broader channel forming processes, with the exception of native fish migration. Flooding in autumn and spring is known to stimulate movement of fish within the channel for spawning, and from the estuary into the lower river for galaxiid and other fish (‘whitebait’) and for elvers (juvenile eels) (e.g. Sloane 1984 a,b,c, Fulton and Pavuk 1988).

Restoration of near-natural trigger floods to restore native fish migration for spawning and recruitment is highly desirable. What limits this option though, is the practical issue that this restoration is unlikely to succeed unless adequate fish passage is provided at key weirs (or such weirs are removed or modified).

Restoration of natural high/flood flow events is likely to significantly benefit biological values in the estuary and Pitt Water through re-establishment of mid-range salinities (see Section 8, and Section 10.3 below).

Overall, we recommend a partial restoration of the natural pattern of high/flood flows, and have based our recommendations largely in-line with the recent historical pattern of events. Philosophically we would recommend the long-term goal of restoring much of the natural flow regime, but only when the broader issues of instream and catchment management are evaluated in detail.

The magnitude, duration and frequency of each of these high flow/flood types were determined for the lower Coal by examination of the historical flow record, as well as data and analyses presented by Hydro Tasmania (1995). An initial minimum set of high flow/floods derived from both the historical and natural flow regimes are shown in Table 9.6.

The ‘compromise’ high/flood flow regime we recommend as part of the overall environmental flow regime for the lower Coal in all ‘normal’ years (annual rainfall between 20 and 80 percentiles) is shown in Table 9.7. It consists of:

- a median flood based on recent historical flows;
- an annual flood with a peak close to the modelled natural event size;
- trigger and fresh events adjusted upward to assist partial restoration of fish passage and pool connectivity and partial flushing of saline pool waters.

We also recommend a reduced high flow/flood regime during drought years (annual rainfalls < 20 percentile), as shown in Table 9.7, with no annual or median flood events and a reduced frequency of both trigger flows and freshes. This broadly mimics the historical pattern which occurs in drought years.

Table 9.6. Size and duration of high/flood flows derived for the Coal River using historical and modelled natural flow data.

	Peak ht (cumec) Historical	Natural	Duration (days)
At Dam			
Median	10.3	13.0	1
Annual	3.3	6.3	1
Trigger	0.5	3.0	1
Freshes	0.2	0.5	0.5
At Richmond			
Median	21.0	26.5	1
Annual	3.0	12.9	1
Trigger	1.0	6.1	1
Freshes	0.4	1.0	0.5

Table 9.7. Recommended initial pattern of high/flood flows for the Coal River, based on historical median and annual floods, and adjusted trigger and fresh events.

	Normal years			Drought years		
	Peak ht (cumec)	**Duration (days)**	**Timing**	**Peak ht (cumec)**	**Duration (days)**	**Timing**
At Dam						
Median	10.0	1	1 per 2 years			
Annual	5.0	1	1 per year			
Trigger	3.0	1	2 per year, spring and autumn	2.0	1	1 per year in autumn
Freshes	0.5	0.5	1 per month, May to November	0.5	0.5	3 per year, May to November
At Richmond						
Median	20.0	1	1 per 2 years			
Annual	10.0	1	1 per year			
Trigger	5.0	1	2 per year, spring and autumn	2.0	1	1 per year in autumn
Freshes	0.5	0.5	1 per month, May to November	0.5	0.5	3 per year, May to November

9.4 Final recommended Environmental Flow regime

The final environmental flow regime is as follows, for both sites:

- minimum baseflows as detailed in Table 9.4, preferably at minimal risk level (with detailed trade-off evaluation and consultation needed to ascertain whether a moderate level of risk should be accepted);
- a sequence of high/flood flow events as detailed in Table 9.7, to be introduced on a trial basis to assess feasibility and likely risks.

Minimum and high/flood flows should be varied in dry years, as indicated in Tables 9.4 and 9.7.

Related recommendations are as follows:

- The state of the instream and estuarine ecosystem should be monitored on a routine basis to assess the efficacy of any environmental flow regime and other related catchment management actions;
- Fish passage requirements should be assessed on the three most downstream weirs in the Coal, and appropriate works conducted to restore a measure of native fish passage;
- An integrated management framework for the riparian zones, environmental flows, land use and sediment erosion, and salinity-water quality should be developed. Both the current Coal River management strategy and the Coal River Care Plan (Ecosynthesis 1999) are inadequate in this regard and need to be broadened or subsumed into a more comprehensive integrated management strategy. It is unlikely that any significant restorative outcomes from future environmental flow management will be observed without these other issues being managed comprehensively.

The typical annual pattern of environmental flows recommended by us for the Coal is shown in Figures 9.4 and 9.5, just downstream of Craigbourne Dam and at Richmond, respectively. This flow regime provides all the major elements of a flow regime for maintaining the existing (though degraded) values of the river and estuarine ecosystems - a seasonal pattern of baseflows, along with high and moderate flood flows with defined frequency, timing and duration.

However one element which is known to be of ecological importance has not been recommended at this stage – cease-to-flow events. In situations where use of the river channel for irrigation supply leads to sustained, constant higher flows in summer-autumn, the provision of cease to flow events is problematic.

Extreme low flows and cessation of flow has been recorded for the Coal River, but is normally accompanied by a natural seasonal flow pattern, and prolonged, slow drawdown allowing the biota to adjust to falling levels. Cessation of flows for short periods without sufficiently slow drawdown would not adequately mimic a natural event and is likely to cause significant deleterious impacts on the river ecosystem. Further evaluation of the use of extreme low flow/cease-to-flow events in regulated rivers in Tasmania is required.

Finally, it should be noted that the minimum flows recommended in this report should otherwise not be significantly interrupted or altered. Any reduction in releases below these levels that occurs due to accident or some other water management problem must be accompanied by supplementary flows to maintain the minimum. In cases where this is not possible, flow reductions must be managed to mimic natural rates of flow decline, to avoid the potentially serious and long-term impacts of abrupt dewatering and stranding events. Rapid, short term rises and falls in river levels can cause mortality in instream biota and exacerbate local erosion within the channel. They should be avoided by the use of appropriate operating rules, with ramping rates, for all major flow controls in the system.

Compliance with the recommended environmental flow provisions should be assessed annually, with the median flood provision being fully reviewed every five years. Two points of compliance are recommended – downstream of Craigbourne Dam, and at Richmond. For the latter, a gauging station should be established on the most downstream weir to ensure sustained delivery of minimum flows to the estuary. Gauging at the Richmond weir alone is insufficient to ensure compliance with environmental flow delivery to the estuary.

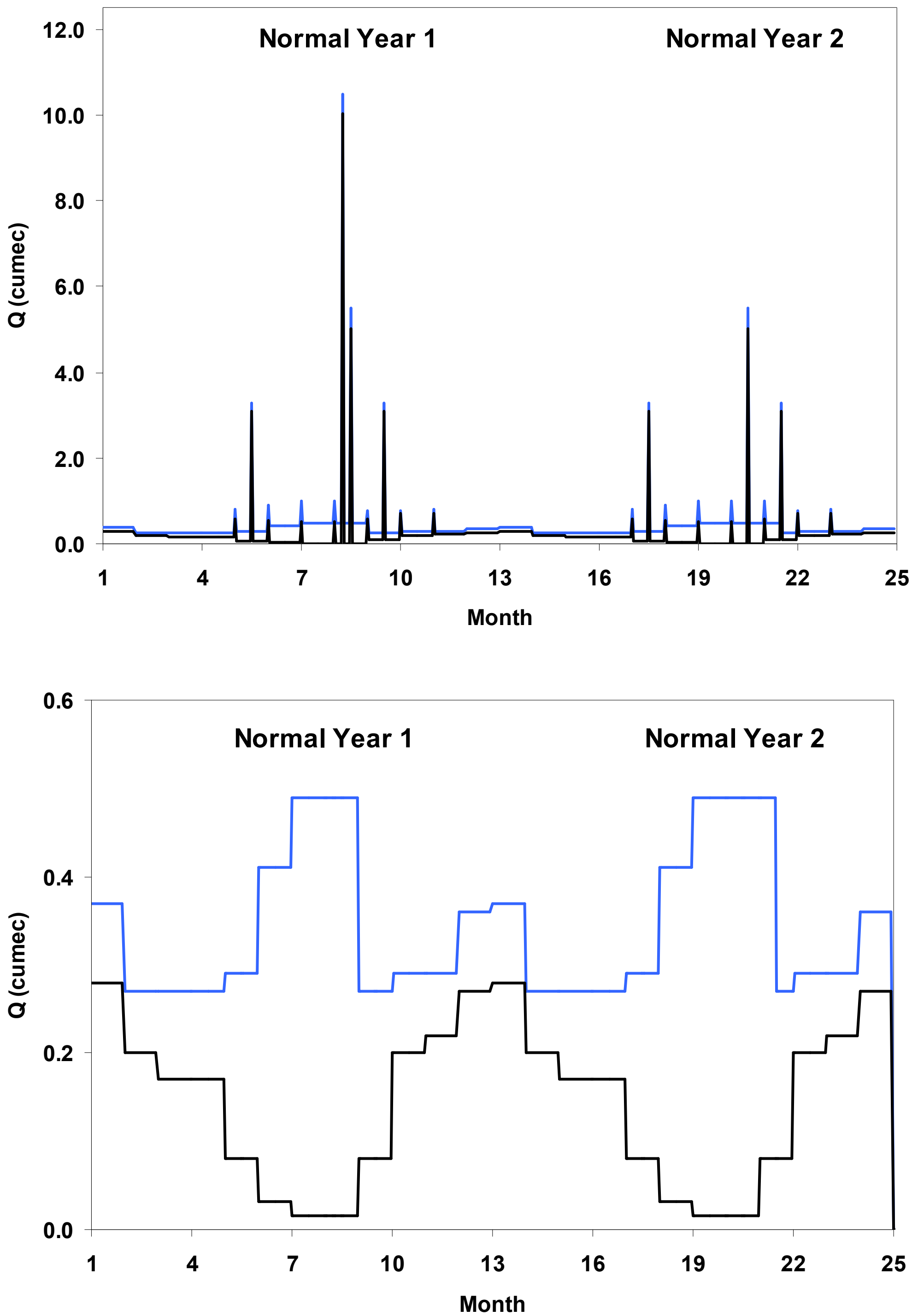
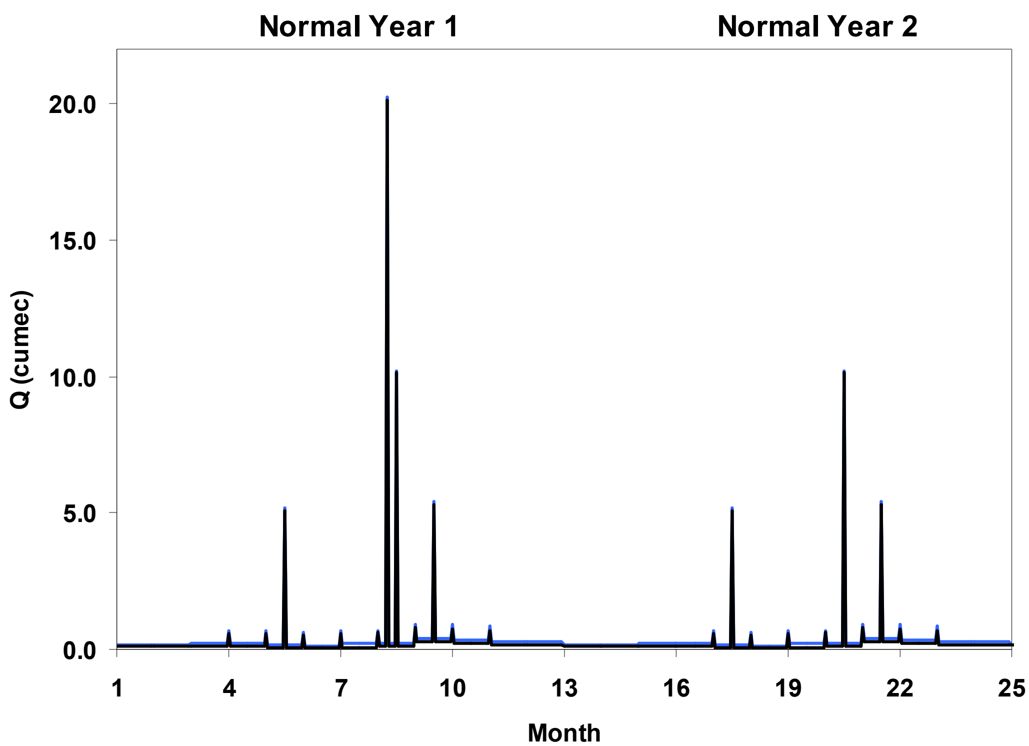


Figure 9.4. Pattern of environmental flows for the Coal River at Craigbourne Dam (Mt Bains). Minimal risk flows are shown for 'normal years' - with and without the median flood release. Black and blue lines show minimum and maximum flows, respectively. Bottom plot shows baseflows only, to illustrate differences between minimum and maximum baseflow values.


Normal Year 1
Normal Year 2
20.0
15.0
10.0
5.0
0.0
Q (cumec)
1
4
7
10
13
16
19
22
25
Month

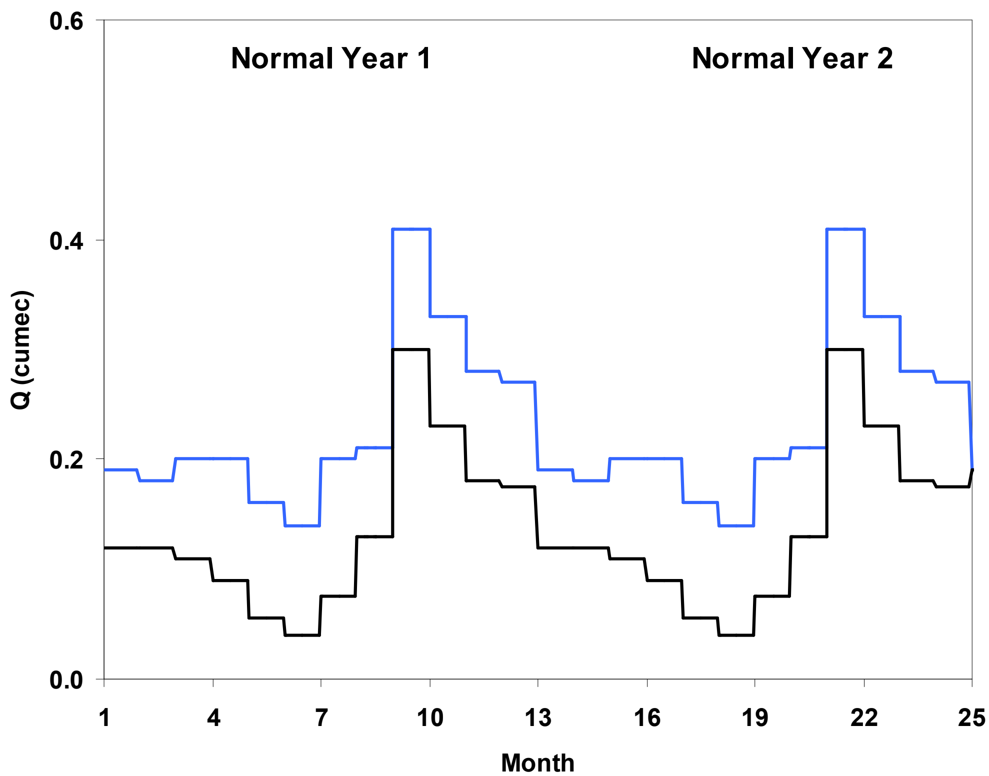

0.6
0.4
0.2
0.0
Normal Year 1
Normal Year 2
Q (cumec)
1
4
7
10
13
16
19
22
25
Month

Figure 9.5. Recommended pattern of environmental flows for the Coal River at Richmond (Daisy Banks), as for Figure 9.4.

10. ENVIRONMENTAL FLOW REGIME – PITT WATER

10.1 Environmental Flow Options

We recognise four major options for flow into Pitt Water estuary as follows:

A maintain existing modified flow regime.

B return to 'natural' flow regime.

C further reduce freshwater flows into Pitt Water, in particular lower base flows, allowing for greater extraction of water for irrigation.

D modify existing flow regime to include more flood events into the estuary.

Firstly, option B of returning to the 'natural' flow regime does not appear to be a feasible option from an ecological or economic perspective. Human activities in the catchment have caused major changes to the natural vegetation and landforms as well as to freshwater flows. The ecosystem has adapted to these changes and any attempts to return to the natural system are only likely to cause additional environmental damage. For example, removal of storage dams, resulting in major floods in Pitt Water estuary after heavy rains, would likely result in greatly increased sedimentation, and concomitant detrimental effects on the estuarine flora and fauna, especially seagrass beds. The community water values also recognise that the extraction of water from the Coal river and tributaries for irrigation is a legitimate and accepted usage of water resources.

Option C, to further reduce freshwater flows into Pitt Water estuary, is also not considered to meet the requirements of ecological sustainability. As discussed above, freshwater flows are required to maintain water quality, estuarine habitats, and the balance between sediment deposition and erosion. Further water extraction would likely result in a marine system with a changed flora and fauna dominated by marine species. In particular, with a reduction in silicate input into the estuary, the phytoplankton community would probably change in dominance from diatoms to nutritionally poor flagellates, and an increased potential for cyanobacterial blooms in upper Pitt Water where the turnover rate is low. This has the potential to result in deleterious water quality and reduced oyster production. The risk of loss of endemic species and special habitats, such as the Ramsar wetlands and seagrass beds, is also substantially increased.

Option A of maintaining the current flow regime is also not considered to be ideal. From the limited data available it appears that the major affect of altered freshwater flow regimes into Pitt Water estuary has been the reduction in frequency of intermediate salinity levels in the range of 27 to 33 ‰ due to a reduced number of annual and trigger flood events. Thus, there is a higher likelihood of subtle and longer-term effects on the flora and fauna of the region, which include reduced breeding success for the extremely rare viviparous sea star, *Patiriella vivipara,* a change in invertebrate fauna from species tolerant of estuarine conditions to marine dominants and possibly reduced attraction to marine fish which utilise estuaries as nursery grounds.

For these reasons, we believe that option D of increasing the flow rates and frequency of flood events into Pitt Water is preferable. The greatest change from natural flows has been found from the assessment and modelling studies to occur in the size and frequency of *annual* and *trigger* floods into the estuary. Flow rates during annual flood events have been estimated to be over four times lower, and trigger floods six times lower, than under natural flow conditions. Given the limited data available on salinity gradients and the lack of baseline studies on the flora and fauna and geomorphology of the estuary, it would be prudent to reduce the extent of change in these medium flows to maintain the health of the estuarine ecosystem. This is particularly so for the upper reaches of the estuary where virtually no information exists on either past or current environmental conditions.

Concomitant with this recommendation for increased minor flood events into the estuary, is the need to manage activities within the catchment to minimise dispersion of sediments from the land into waterways and hence sediment deposition in the estuary. Reduced sedimentation and hence increased light penetration in the estuary is highly likely to improve primary production and stability of sea grass beds in Pitt Water, with an overall improvement in the health of the estuary.

10.2 Qualitative Risk Assessment of the Effects of Existing Freshwater Flows

A qualitative risk assessment was conducted to further assess the impact of current freshwater flows into Pitt Water estuary. This assessment was using the joint Australian/New Zealand Standard for Risk Management (1999). Risk has been defined as: 'the likelihood of an undesired event occurring as a result of some behaviour or action (including no action) and risk assessment as: 'the means by which the frequency and consequences of such events are determined' (Hayes 1997). Hazards (potential risks) for this assessment were identified from the environmental values that have been described for Pitt Water estuary.

A description of the qualitative levels of *consequences* of the existing (i.e. recent historical) freshwater flow regime from the Coal River is provided in Table 10.1. The *likelihood* of these consequences occurring was assessed using standard descriptors from Australian/New Zealand Standards (1999), shown in Table 10.2. The two measures, *consequence* and *likelihood*, were combined in a qualitative risk analysis matrix (Table 10.3). This risk analysis matrix was then used to define the potential *levels of risk* from the existing freshwater flow regime into Pitt Water for the key environmental values identified earlier (Table 10.4).

Table 10.1. Qualitative measures of consequences for risk assessment.

Level	Descriptor	Detailed Description
1	Insignificant	Changes to the environment are not readily detectable and are short term
2	Minor	Minor adverse environmental effects in the estuary, small changes in species diversity and abundance of fauna and flora.
3	Moderate	Medium environmental impact, characterised by significant changes to species composition and abundance, reduced abundance of endemic species, increased sedimentation in the estuary, reduced economic and aesthetic value.
4	Major	Large and widespread environmental damage, significant increase in sedimentation, major changes to biota, fauna and flora dominated by pollutant indicator species or introduced pests, species diversity very low, major decline in economic and aesthetic values.

Table 10.2. Qualitative measures of likelihood for risk assessment.

Level	Descriptor	Description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May only occur in exceptional circumstances

Table 10.3. Qualitative risk analysis matrix - level of risk. E: extreme risk, H: high risk, M: moderate risk, L: low risk

	Consequence			
Likelihood	**Insignificant 1**	**Minor 2**	**Moderate 3**	**Major 4**
A (almost certain)	H	H	E	E
B (likely)	M	H	H	E
C (moderate)	L	M	H	E
D (unlikely)	L	L	M	H
E (rare)	L	L	M	H

Table 10.4. Risk register for Pitt Water estuary. Activity: maintaining existing freshwater flow regime from the Coal River into Pitt Water estuary.

Risk	Consequence Rating	Likelihood Rating	Level of Risk
Loss of endemic species	3	C	H
Alteration to size and composition of RAMSAR wetlands	3	D	M
Decline in recreational activities in the estuary	1	D	L
Reduced production of oysters and finfish	3	C	H
Habitat loss, especially seagrass beds, and reduction in natural biodiversity	3	C	H
Reduced aesthetic values and tourism potential	2	D	L

Although this qualitative risk assessment could be considered to be subjective, we have attempted to take a relatively conservative approach. From the risk assessment, there is a high risk that the existing flow regime into Pitt Water could result in habitat loss and associated reduction in natural biodiversity. Loss of endemic species and economic value from shellfish production is also at high risk. However, changes to wetlands are thought to be less likely to occur and so this risk was considered to be at a medium level. Recreational activities and reduced aesthetic values are believed be at low risk levels with the existing flow regime.

This risk assessment further emphasises that present day flow regimes into Pitt Water are unlikely to support the ecosystem processes and PEVs that have been determined for Pitt Water estuary.

10.3 Quantitative assessment of the effect of changes in flow on salinity.

Given the high risks of significant ecological consequences associated with the current flow regime (Table 10.4) it is important to assess how adopting the proposed flow regime (Table 9.7) would effect salinity levels seen in the estuary. Changes in the salinity indicate how increased flows will improve environmental conditions in the estuary and allow some estimation of how the risks outlined in Table 10.4 are alleviated.

The effect of the proposed minimum environmental flows (derived in Section 9 for the Coal River) on Pittwater estuary and the difference between 'natural' and current flood regime (Figures 1.3 and 1.4) were modelled using the predicted relationship between flow and salinity shown in Figure 8.3. Note that the predictability from these base flows is necessarily coarse due to the relative invariance of the base flows compared to the flows used for Figure 8.7.

Figure 10.1 shows the effects on the salinity levels at Shark Point of the proposed:

1) minimum environmental baseflows (at Risk level I, see Richmond figures in Table 9.4); and

2) their capped maximum values (see Table 9.5, adjusted for lower catchment inputs);

combined with:

3) the environmental high flow/flood regime based on historical flow data (see Richmond figures, Table 9.6); or

4) the environmental high flow/flood regime based on modelled natural flow data (see Richmond figures, Table 9.6).

Figure 10.1a shows the salinity levels derived from the combination of 2 and 3, while Figure10.1b shows salinity predicted from the combination of 2 and 4. Figure10.1c shows the salinity levels with the combination of 1 and 3, and Figure10.1d shows salinity levels with both 1 and 4.

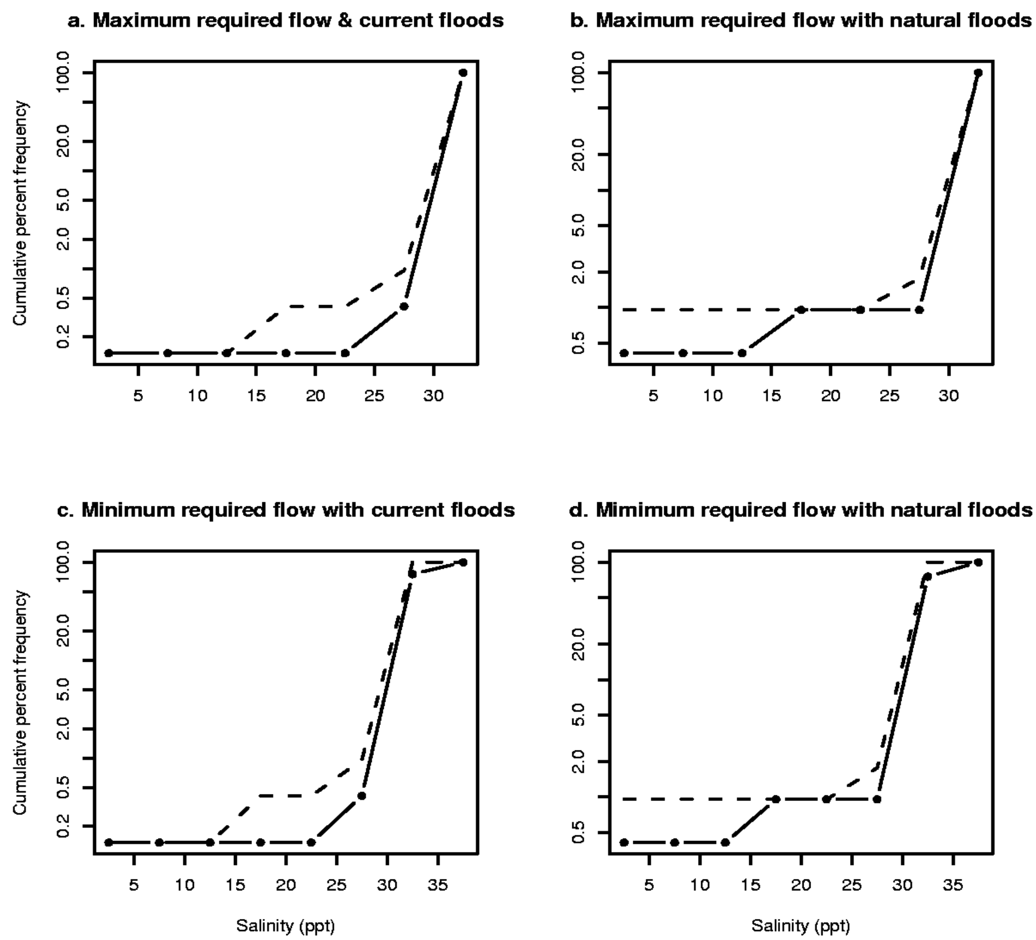


Figure 10.1. The effect of proposed flows from the Coal river on salinity frequency distributions at Shark Point. Solid lines show the predicted relationship and dashed lines the upper 95% prediction confidence interval. Note current and natural floods = environmental high/flood flow regimes derived from recent historical or modelled natural flow data, respectively.

Differences in salinity between maximum (capped) and minimum environmental flows are small (comparing Figure 10.1 a with c, or 10.1b with d). Under either scenario, the estuary tends to stay at or near marine salinity levels. Note, however, that the minimum environmental flows infrequently produce higher salinity values (i.e. far right of Figures 10.1c & 10.1d) than do the maximum (cap) environmental flows.

Likewise, there is very little difference in salinity levels or their frequency derived from 'natural' or 'historical' *median* flood flows (comparing the left hand end of plots in Figure 10.1a with b or in Figure 10.1 c with d).

The greatest difference in salinity between the 'natural' or 'historical' flood flow regimes occurs at intermediate salinity levels. *Annual* and *trigger* 'natural' flood flows depress salinity to the intermediate ranges lacking in the historical flow regime (Figure 8.8). These intermediate salinity levels are approximately twice as likely with the 'natural' than the 'historical' annual and trigger flood flows, and occur irrespective of the minimum environmental flow levels (see the mid-sections of plots in Figures 10.1b and 10.1d).

10.4 Environmental Flow regime for Pitt Water

The results of assessment of the current condition and historical changes in Pitt Water, though limited by lack of data, as well as the qualitative risk assessment, force us to conclude that the estuary is degraded and is at high risk of further degradation under the existing flow regime in a number of key environmental values.

Several values in the estuary would be under much greater risk if base and high/flood flows were reduced in magnitude and frequency than they are now.

We therefore believe that a minimum environmental flow regime is required which sets a lower limit for existing flow discharge to the estuary. The minimum flows identified for low to moderate risks for the Coal River and shown in Table 9.4 are also relevant and applicable to the estuary.

We have concluded that the provision of high/flood flows is not essential for maintaining the nutrient (N and P) supply to the estuary, but are essential for maintaining silicate levels and hence for maintaining diatom algal populations, the favoured food source of commercial oysters. Flood flows of 2 – 10 cumec are required to raise Pitt Water Si concentrations to desired peak levels above 500 microg/l.

Another key parameter in the relationship between environmental values and freshwater flows in Pitt Water is salinity, particularly its variation and the need for intermediate levels of fluctuation in the salinity range 10-30 ppt. This salinity range is important for a number of values including saltmarsh and seagrass vegetation, mid-estuarine and intertidal benthic invertebrates, juvenile flounder and reproduction of the locally endemic *Patiriella* starfish. The restoration of the recommended annual and trigger flood events to the estuary, derived using the 'natural' flow data, would restore this variation and assist in protecting these values.

We would therefore recommend the adoption of an environmental high/flood flow regime with annual and trigger events close in magnitude to those derived in Table 9.6 from 'natural' flow data. The 'compromise' high/flood flows shown in Table 9.7 would also largely satisfy these requirements.

11. RECOMMENDATIONS

11.1 Environmental Flows

We recommend implementation of an environmental flow regime in the lower Coal River, downstream of Craigbourne Dam, with:

1. the minimum flow regime for minimal risk (Risk Band I boundary) shown in Table 9.4;
2. minimum flows capped in accordance with Table 9.5 through upper limits to Craigbourne releases, other than during high/flood flow events;
3. a high/flood flow regime shown in Table 9.7.

The intended outcomes of this environmental flow regime are:

- to maintain existing biological and related values in the lower Coal River and Pitt Water by maintaining minimum (base) flows within a range similar to that observed under current irrigation management (i.e. since construction of Craigbourne Dam);
- to prevent further loss of biodiversity in Pitt Water by partially restoring the natural range of salinities, by the use of annual and trigger flood events;
- to prevent further contraction of the lower Coal River channel due to instream sediment accumulation and vegetation encroachment, and limit the risk of major erosion events during very large floods, by restoration of an annual high flow event;
- to partially restore native fish populations in the lower Coal by re-introduction of trigger flow events in autumn (to enhance spawning), and spring (to enhance upstream migration and recruitment);
- to maintain pool connectivity (to support fish habitat requirements), support native aquatic vegetation and reduce the risk of high pool salinities during low flows, by maintaining a pattern of small flow pulses or freshes throughout the non-irrigation season.

The above regime may also have the consequence of protecting/enhancing the recreational brown trout fishery – a value identified in community consultation.

The environmental flow regime should be implemented by a specific release strategy from Craigbourne Dam, coupled with operating rules which facilitate release of high/flood flows ate the times designated in Table 9.7 and during rain events to coincide with higher flows in the lower catchment where possible.

Care should be taken to minimise contamination of the lower Coal with high levels of blue green algae, by controlling releases during blooms in the Craigbourne Dam storage.

Compliance with the environmental flow regime should be assessed at two gauging stations:

- just downstream of Craigbourne Dam; and
- at a gauging station at weir near Richmond (preferably at the most downstream weir, due to the problems with lack of control over abstractions and releases from that weir into the estuary).

Compliance should focus on flow delivery:

- at or above the recommended minimum mean daily flows in each month;
- at the recommended magnitude and at the right seasonal timing, as well as at the recommended average frequency for each high/flood flow event.

Irrigation flow management and environmental flow delivery should also comply with a requirement to minimise rapid rises and falls in river level so as to reduce risks of bank failure.

Compliance with the environmental flow regime should be reported and reviewed annually, and should feed back into management of Craigbourne Dam releases and into water management for irrigation throughout the lower Coal valley.

Monitoring of environmental outcomes should also be seen as an integral part of water management for the lower Coal and of environmental flows within that water management.

11.2 Broader Management Issues

The Coal River is in a degraded condition, as is at least the upper Part of the Pitt Water estuary. A combination of factors appear to be responsible for this. As indicated earlier, implementation of environmental flows alone will not fully maintain or even partially restore some of the key environmental values identified for the lower Coal and Pitt Water.

If a desire to significantly restore aspects of this ecosystem is voiced by the community, which has not been happened to date, a much more focused and integrated management strategy is required which tackles, among other issues:

- Sediment sources in the catchment and drainage network, and sediment fate in the river and estuary;
- Riparian land and vegetation management and rehabilitation in both the river and upper Pitt Water;
- Water quality, particularly salinity in the river;
- Restoration and maintenance of native fish passage in the lower Coal.

11.3 Further Investigations and Data Needs

In order to support implementation of the environmental flow regime, we recommend the following as essential investigations or activities for the Coal River:

- Continuance of the water monitoring program for nutrients in the lower Coal, particularly in the vicinity of Richmond, and expansion to include event monitoring and analysis of silicate. This should then be analysed to assess nutrient and silicate loads to the estuary.
- Improvement of data collection on flows at the lower end of the Coal at the Richmond weir, and establishment of a gauging station on the most downstream weir.
- Ongoing monitoring of fish populations in the lower Coal.
- A survey of current channel cross-sections and continued monitoring, to reveal any potential alterations in channel stability.
- Quantitative assessment of aerial photographs to determine the degree and rate of change in channel contraction and associated vegetation (willow) invasion into the

channel, pre- and post dam construction, to provide a baseline for future monitoring.

These investigations are required for Pitt Water:

- Monitoring of salinity regimes and survey and monitoring of the aquatic flora and fauna and sedimentation rates in Upper Pitt Water, especially between Lands End and Richmond, (currently no information is available for this region).
- Ongoing monitoring of the area of seagrass beds and wetlands in Pitt Water.
- Ongoing monitoring of the population of the endemic seastar in the estuary.
- Assessment of N and P cycling in Pitt Water, in particular loadings from freshwater flow during flood events, and losses due to denitrification.
- Evaluation of sediment transport into Pitt Water, particularly during floods, and the effects on the Ramsar wetlands.

Further, desirable investigations include:

- Assessment of the effects of flow variation on willow colonization in the lower Coal.
- Assessment of the effects of willow removal and channelisation on channel geometry and flows in the lower Coal.
- Investigation of the effects of flow variation on floodplain wetlands.
- Long term monitoring and comparative studies on the changes in lower Coal River turbidity and substrate composition.

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APPENDIX 1.

Minimum Flow Hydraulic and Habitat data for Mt Bains and Daisy banks.

Coal at Daisy Banks - final RHYHAB habitat/hydraulic data.

```
BED   DATA  'V'   'Si'  'S'   'F'   'G'   'C'   'B'   'Be'
0     'DB-T0'     8.8
GAU   8.69  0.032
GAU   8.707 0.023
SZF   8.11
0     -1.159      0     0     100   0     0     0     0     0     0
1     -0.862      0     0     100   0     0     0     0     0     0
1.8   -0.399      0     0     100   0     0     0     0     0     0
2     0     0     0     100   0     0     0     0     0     0
2.4   1.876 0     0     100   0     0     0     0     0     0
3.1   1.925 0.01  0     50    0     0     0     0     50    0
3.8   1.764 0.01  0     40    0     10    10    0     40    0
4.4   1.938 0     0     20    0     60    20    0     0     0
5     1.893 0     0     20    0     50    20    0     10    0
5.5   1.884 0     0     10    0     30    10    0     50    0
6.1   1.7   0     0     10    0     15    15    0     60    0
6.7   1.557 0     0     10    0     30    20    0     40    0
7.2   1.405 0     0     10    0     20    20    0     50    0
7.8   1.357 0     0     30    10    30    30    0     0     0
8.3   1.256 0     0     40    10    20    15    0     15    0
8.9   1.096 0     0     50    10    15    10    0     15    0
9.5   1.878 0     0     60    10    15    5     0     10    0
10.1  0.641 0     0     70    10    10    0     10    0     0
10.7  0     0     0     95    5     0     0     0     0     0
11    -0.459      0     0     100   0     0     0     0     0     0
12.1  -0.548      0     0     85    0     0     5     10    0     0
13    -0.799      0     0     80    0     0     0     20    0     0
14    -1.004      0     0     55    0     0     5     10    30    0
15.1  -1.33 0     0     30    0     0     20    10    40    0
END
12.1  'DB-T1'     9.8
GAU   9.74  0.032
GAU   9.762 0.023
SZF   8.96
0     -1.158      0     0     100   0     0     0     0     0     0
1.1   -0.712      0     0     100   0     0     0     0     0     0
1.6   -0.543      0     0     100   0     0     0     0     0     0
2     -0.272      0     0     100   0     0     0     0     0     0
2.3   0     0     0     80    0     20    0     0     0     0
2.7   0.084 0     0     50    0     10    40    0     0     0
3.3   0.209 0     0     40    0     0     20    20    10    10
4     0.905 0     0     20    0     0     20    30    30    0
4.5   0.84  0     0     10    0     0     40    40    10    0
5     0.792 0     0     20    0     0     45    30    5     0
5.5   0.787 0.02  0     20    0     0     60    20    0     0
6     0.741 0.02  0     10    0     0     60    30    0     0
6.5   0.684 0.02  0     5     0     0     40    50    5     0
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```
7     0.613 0.02  0     0     0     10    40    45    5     0
7.5   0.536 0.01  0     10    0     5     40    40    5     0
8     0.41  0     0     20    0     0     40    30    10    0
8.5   0.272 0     0     15    0     0     40    40    5     0
9     0.143 0     0     20    0     10    30    35    5     0
9.5   0.126 0     0     30    0     0     40    30    0     0
10    0.102 0     0     30    0     0     40    30    0     0
10.8  0.066 0     0     40    0     0     40    20    0     0
11.2  0     0     0     50    0     0     30    20    0     0
11.9  -0.35 0     0     50    0     0     40    10    0     0
13.7  -0.975      0     0     70    0     0     20    10    0     0
15.5  -1.485      0     0     100   0     0     0     0     0     0
18    -1.417      0     0     90    0     0     0     10    0     0
END
22.1  'DB-T2'     10.9
GAU   10.84 0.032
GAU   10.836      0.023
SZF   10.21
0     -1.056      0     0     100   0     0     0     0     0     0
1.5   -0.885      0     0     100   0     0     0     0     0     0
2.7   -0.545      0     0     100   0     0     0     0     0     0
3.5   -0.144      0     0     90    0     0     10    0     0     0
3.6   0     0     0     90    0     0     10    0     0     0
3.75  0.637 0     0     80    0     10    10    0     0     0
3.8   0.649 0     0     80    0     10    10    0     0     0
4.3   0.711 0.07  0     0     0     10    20    60    10    0
4.7   0.722 0.07  0     0     0     0     40    50    10    0
5.2   0.703 0.01  0     10    0     5     35    50    0     0
5.5   0.667 0.01  0     10    0     0     40    50    0     0
6     0.572 0     0     10    0     0     40    50    0     0
6.5   0.504 0     0     10    0     10    30    50    0     0
7.2   0.365 0     0     0     0     10    30    60    0     0
7.9   0.214 0     0     0     0     20    35    40    5     0
8.8   0.076 0     0     0     0     10    20    60    0     10
9.8   0.015 0     0     10    0     10    50    30    0     0
10.1  0     0     0     50    0     10    30    10    0     0
10.8  -0.309      0     0     90    0     0     10    0     0     0
11.5  -0.637      0     0     90    0     0     10    0     0     0
13.4  -1.008      0     0     90    0     5     5     0     0     0
13.7  -1.294      0     0     90    0     5     5     0     0     0
15.4  -1.32 0     0     95    0     0     0     5     0     0
16.7  -1.378      0     0     80    0     0     0     20    0     0
END
41.6  'DB-T3'     11.5
GAU   11.46 0.032
GAU   11.39 0.023
SZF   10.81
0     -1.434      0     0     100   0     0     0     0     0     0
1     -1.112      0     0     100   0     0     0     0     0     0
2.4   -0.687      0     0     100   0     0     0     0     0     0
2.8   -0.362      0     0     100   0     0     0     0     0     0
3.5   -0.168      0     0     100   0     0     0     0     0     0
3.75  0     0     0     100   0     0     0     0     0     0
3.9   0.088 0     0     100   0     0     0     0     0     0
4.05  0.094 0     0     100   0     0     0     0     0     0
4.5   0.59  0     0     100   0     0     0     0     0     0
4.9   0.564 0.02  0     65    0     0     0     30    5     0
5     0.776 0.02  0     50    0     0     10    35    5     0
5.5   0.796 0.02  0     0     0     0     35    60    5     0
6     0.737 0.02  0     0     0     0     30    60    10    0
6.7   0.646 0.01  0     0     0     0     30    70    0     0
```

```
7.2   0.51  0     0     0     0     0     20    80    0     0
7.9   0.386 0     0     0     0     0     20    50    30    0
8.5   0.266 0     0     0     0     0     30    50    20    0
9     0.045 0     0     30    0     0     10    50    10    0
9.4   0     0     0     70    0     0     0     20    10    0
10    -0.323      0     0     90    0     0     0     0     10    0
11    -0.654      0     0     90    0     0     0     10    0     0
12.5  -0.88 0     0     95    0     0     5     0     0     0
13.6  -1.064      0     0     80    0     0     10    5     5     0
15    -1.297      0     0     70    0     0     20    10    0     0
END
61.1  'DB-T4'     12.7
GAU   12.7  0.032
GAU   12.637      0.023
SZF   11.738
0     -1.192      0     0     100   0     0     0     0     0     0
1     -1.086      0     0     100   0     0     0     0     0     0
2.6   -0.745      0     0     100   0     0     0     0     0     0
2.8   -0.578      0     0     100   0     0     0     0     0     0
3.3   -0.23 0     0     90    0     10    0     0     0     0
3.4   0     0     0     50    10    20    20    0     0     0
3.45  0.3   0     0     50    10    20    20    0     0     0
3.63  0.62  0     0     50    10    20    20    0     0     0
4.2   0.758 0     0     0     10    25    60    5     0     0
5.2   0.879 0     0     0     0     10    50    35    5     0
6.2   0.849 0.02  0     0     0     10    50    40    0     0
7.2   0.78  0.01  0     0     0     10    40    50    0     0
8.2   0.822 0.01  0     0     0     10    50    40    0     0
9.2   0.78  0.01  0     0     0     20    45    30    5     0
10.2  0.768 0     0     20    0     50    30    0     0     0
11.2  0.962 0     0     50    10    30    10    0     0     0
12.2  1.08  0     0     100   0     0     0     0     0     0
13.2  1.095 0     0     90    0     0     10    0     0     0
14.2  0.995 0     0     40    0     20    20    20    0     0
15.2  0.802 0     0     90    0     0     10    0     0     0
15.6  0.15  0     0     100   0     0     0     0     0     0
15.66 0.004 0     0     100   0     0     0     0     0     0
15.8  0     0     0     100   0     0     0     0     0     0
16.6  -0.612      0     0     100   0     0     0     0     0     0
18    -0.95 0     0     100   0     0     0     0     0     0
20    -1.128      0     0     100   0     0     0     0     0     0
END
89.6  'DB-T5'     14.4
GAU   14.33 0.032
GAU   14.321      0.023
SZF   13.6498
0     -0.5468     0     0     60    0     0     40    0     0     0
0.7   -0.4788     0     0     65    0     0     30    5     0     0
1.5   -0.4948     0     0     35    0     10    40    10    5     0
2.5   -0.3368     0     0     70    0     0     20    10    0     0
2.7   0     0     0     85    0     10    0     5     0     0
3.2   0.2722      0     0     40    0     45    10    5     0     0
3.6   0.4172      0     0     10    0     15    15    10    0     50
4.1   0.4982      0.01  0     0     0     0     0     0     0     100
4.6   0.5052      0.02  0     0     0     0     0     0     0     100
4.9   0.5082      0.03  0     0     0     0     0     0     0     100
5.2   0.5362      0.02  0     0     0     0     0     0     0     100
5.4   0.5802      0.03  0     0     0     0     0     0     0     100
5.6   0.4902      0.02  0     0     0     0     0     0     0     100
6     0.4902      0.01  0     0     0     0     0     0     0     100
6.4   0.4982      0.01  0     0     0     0     0     0     0     100
```

```
6.65  0.7502      0.01  0     0     0     0     0     0     0     100
7     0.7252      0.01  0     0     0     0     0     0     0     100
7.5   0.5562      0.01  0     30    0     0     0     0     20    50
8.05  0     0     0     45    0     0     5     20    30    0
9     -0.3118     0     0     60    0     0     0     20    20    0
10    -0.5988     0     0     80    0     0     0     5     15    0
10.8  -1.2418     0     0     40    0     0     10    30    20    0
END
130.6 'DB-T6'     15.2
GAU   15.13 0.032
GAU   15.389      0.849
GAU   15.108      0.023
SZF   15.048
0     -0.709      0     0     100   0     0     0     0     0     0
0.7   -0.572      0     0     100   0     0     0     0     0     0
1.4   -0.298      0     0     95    0     0     0     5     0     0

1.9   -0.108      0     0     100   0     0     0     0     0     0
2.6   -0.099      0     0     95    0     0     0     5     0     0
3.45  0     0     0     90    0     0     0     10    0     0
3.85  0.102 0.32  0     55    0     0     0     20    25    0
4.3   0.051 0.46  0     10    0     0     0     10    80    0
4.6   0.036 0.06  0     0     0     0     0     40    60    0
4.9   0.046 0.83  0     0     0     0     0     40    60    0
5.35  0.165 0.48  0     0     0     0     0     20    80    0
5.6   0.004 0     0     0     0     0     0     10    90    0
5.9   0.101 0.36  0     0     0     0     0     0     100   0
6.25  0.031 0.29  0     0     0     0     0     40    60    0
6.5   0.142 0.28  0     0     0     0     0     50    50    0
6.9   0.152 0.17  0     0     0     0     0     20    80    0
7.2   0.107 0.48  0     50    0     0     0     0     50    0
7.4   0     0     0     80    0     0     0     0     20    0
7.95  -0.045      0     0     95    0     0     0     0     5     0
8.7   -0.12 0     0     95    0     0     0     0     5     0
9.4   -0.405      0     0     95    0     0     0     0     5     0
10.3  -0.789      0     0     70    0     0     0     0     30    0
11.3  -1.09 0     0     80    0     0     0     15    5     0
END
145   'DB-T7'     15.9
GAU   15.8  0.032
GAU   16.096      0.849
GAU   15.787      0.023
SZF   15.57
0     -0.985      0     0     100   0     0     0     0     0     0
1     -0.824      0     0     100   0     0     0     0     0     0
2     -0.39 0     0     100   0     0     0     0     0     0
2.1   -0.246      0     0     100   0     0     0     0     0     0
3     -0.158      0     0     80    0     0     0     0     20    0
3.8   -0.122      0     0     80    0     0     0     0     20    0
4.05  0     0     0     40    0     0     0     30    30    0
4.3   0.14  0     0     20    0     0     0     30    50    0
4.6   0.178 0.08  0     20    0     0     0     30    50    0
4.9   0.005 0     0     10    0     0     0     30    60    0
5.15  0.177 0.12  0     5     0     0     5     30    60    0
5.4   0.289 0.05  0     10    0     0     10    30    50    0
5.7   0.311 0.25  0     0     0     0     20    50    30    0
6     0.296 0.15  0     0     0     0     20    50    30    0
6.3   0.274 0     0     0     0     0     20    40    40    0
6.6   0.221 0.18  0     0     0     0     10    60    30    0
6.9   0.179 0.11  0     0     0     0     10    70    20    0
7.2   0.182 0.14  0     0     0     0     10    90    0     0
```

```
7.5   0.205 0.12  0     0     0     0     10    90    0     0
7.8   0.188 0.02  0     0     0     0     10    90    0     0
8.4   0     0     0     20    0     0     20    30    30    0
8.8   -0.251      0     0     0     0     0     20    20    60    0
9.3   -0.532      0     0     50    0     0     0     20    30    0
10.3  -0.752      0     0     90    0     0     0     0     10    0
12.3  -1.268      0     0     90    0     0     0     0     10    0
END
164.9 'DB-T8'     17.3
GAU   17.23 0.032
GAU   17.513      0.849
GAU   17.221      0.023
SZF   16.377
0     -0.644      0     0     100   0     0     0     0     0     0
0.8   -0.317      0     0     100   0     0     0     0     0     0
1.8   -0.211      0     0     100   0     0     0     0     0     0
2.9   -0.079      0     0     100   0     0     0     0     0     0
3.35  0     0     0     100   0     0     0     0     0     0
4     0.051 0     0     95    0     0     0     5     0     0
4.8   0.401 0     0     60    0     20    20    0     0     0
5.5   0.608 0.04  0     30    0     20    50    0     0     0
6.1   0.784 0.04  0     20    0     25    50    0     0     5
6.7   0.923 0     0     15    0     0     30    5     0     50
7.3   0.892 0     0     10    0     0     10    0     0     80
7.9   0.74  0     0     0     0     0     0     0     0     100
8.5   0.695 0     0     0     0     0     0     0     0     100
9.1   0.651 0     0     0     0     0     0     0     0     100
9.7   0.681 0     0     0     0     0     0     0     0     100
10.3  0.664 0     0     0     0     0     0     0     0     100
10.9  0.681 0     0     0     0     0     0     0     5     95
11.5  0.644 0     0     0     0     0     0     0     5     95
12.45 0     0     0     50    0     0     0     0     0     50
12.8  -0.389      0     0     100   0     0     0     0     0     0
13    -1.013      0     0     100   0     0     0     0     0     0
13.8  -1.091      0     0     100   0     0     0     0     0     0
15.3  -1.051      0     0     100   0     0     0     0     0     0
END
217.6 'DB-T9'     17.8
GAU   17.7  0.032
GAU   18.121      0.849
GAU   17.72 0.023
SZF   17.615
0     -1.152      0     0     90    0     5     5     0     0     0
1.5   -1.007      0     0     100   0     0     0     0     0     0
2.7   -0.659      0     0     100   0     0     0     0     0     0
3.5   -0.457      0     0     70    0     0     0     30    0     0
4.6   -0.23 0     0     100   0     0     0     0     0     0
6     -0.178      0     0     100   0     0     0     0     0     0
7.7   -0.168      0     0     90    0     0     10    0     0     0
8.6   -0.071      0     0     55    0     10    30    5     0     0
9.5   -0.141      0     0     100   0     0     0     0     0     0
10.1  -0.473      0     0     100   0     0     0     0     0     0
10.9  -0.201      0     0     90    0     0     10    0     0     0
12.15 -0.041      0     0     25    0     10    50    10    5     0
13.25 0     0     0     15    0     10    50    20    5     0
13.9  0.042 0     0     0     0     10    50    30    10    0
14.3  0.095 0.11  0     0     0     10    50    30    10    0
14.6  0.108 0.14  0     0     0     0     20    50    30    0
15.2  0.109 0.28  0     0     0     0     10    45    45    0
15.4  0.153 0.15  0     0     0     0     10    40    50    0
15.8  0.176 0.33  0     0     0     0     0     50    50    0
```

```
16.1  0.181 0.26  0     0     0     0     10    40    50    0
16.4  0.185 0.3   0     0     0     0     10    50    40    0
16.7  0.007 0.23  0     0     0     0     10    50    40    0
16.95 0.159 0.14  0     0     0     0     20    60    20    0
17.2  0.108 0.24  0     0     0     10    20    50    20    0
17.5  0.08  0     0     20    0     25    30    20    5     0
17.7  0     0     0     50    0     20    10    10    10    0
18.4  -0.142      0     0     70    0     0     30    0     0     0
19.5  -0.283      0     0     60    0     0     40    0     0     0
21    -0.363      0     0     90    0     0     10    0     0     0
22.3  -0.734      0     0     100   0     0     0     0     0     0
23    -1.151      0     0     100   0     0     0     0     0     0
END
237.6 'DB-T10'    18.7
GAU   18.64 0.032
GAU   18.618      0.023
SZF   18.01
0     -2.208      0     0     100   0     0     0     0     0     0
0.8   -2.215      0     0     100   0     0     0     0     0     0
1.2   -1.57 0     0     100   0     0     0     0     0     0
2     -1.309      0     0     100   0     0     0     0     0     0
3.8   -0.877      0     0     95    0     0     0     5     0     0
4.6   -0.395      0     0     70    0     0     10    20    0     0
5.6   -0.164      0     0     100   0     0     0     0     0     0
6.5   0     0     0     95    0     0     0     5     0     0
7.6   0.242 0     0     100   0     0     0     0     0     0
8.8   0.725 0     0     50    0     0     0     50    0     0
10    0.947 0     0     30    0     0     20    50    0     0

11.1  1.016 0.01  0     20    0     0     50    30    0     0
12.2  1.034 0     0     20    0     0     40    40    0     0
13.4  1.005 0     0     10    0     0     70    20    0     0
14.5  0.829 0     0     20    0     10    50    20    0     0
15.6  0.729 0     0     15    0     10    60    15    0     0
16.8  0.447 0     0     10    0     60    30    0     0     0
17.9  0.258 0     0     20    0     50    30    0     0     0
19    0.149 0     0     30    0     50    20    0     0     0
20.2  0.097 0     0     50    0     40    10    0     0     0
21.7  0     0     0     100   0     0     0     0     0     0
22.9  -0.026      0     0     100   0     0     0     0     0     0
23.5  -0.513      0     0     100   0     0     0     0     0     0
25.5  -1.135      0     0     100   0     0     0     0     0     0
28    -1.384      0     0     100   0     0     0     0     0     0
END
END
```

Coal at Daisy Banks - Habitat preference data.

```
Austrocercoides sp.'

DEP   0.10  0.21  0.40  0.61  0.81

WEI   0.86  1.00  0.00  0.19  0.00

VEL   0     0.06  0.19  0.38  0.55

WEI   0.05  0.00  1.00  0.02  0.12

SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
```

```
WEI   0.00  0.88  0.00  0.00  0.03  0.25  1.00  0.00

END

Nousia sp. (total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.10  1.00  0.02  0.02  0.01

VEL   0     0.06  0.19  0.38  0.55

WEI   0.01  0.01  0.06  0.05  1.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.03  0.00  0.01  0.04  0.02  1.00  0.01

END

Atalophlebia sp. (total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.55  1.00  0.65  0.28  0.31

VEL   0     0.06  0.19  0.38  0.55

WEI   0.41  0.21  1.00  0.45  0.05

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.34  0.00  0.03  0.38  0.60  1.00  0.03

END

Tasmanocoenis sp. (total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.89  0.74  1.00  0.95  0.75

VEL   0     0.06  0.19  0.38  0.55

WEI   1.00  0.53  0.25  0.05  0.26

SUB   1     2     3     4     5     6     7     8

WEI   0.00  1.00  0.00  0.85  0.30  0.64  0.42  0.85

END

Atriplectides dubius'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.85  0.56  0.19  0.00  1.00

VEL   0     0.06  0.19  0.38  0.55
```

WEI 1.00 0.00 0.00 0.00 0.00

SUB 1 2 3 4 5 6 7 8

WEI 0.00 0.39 0.00 1.00 0.13 0.73 0.00 0.00

END

Lingora aurata'

DEP 0.11 0.21 0.40 0.61 0.81

WEI 0.12 1.00 0.32 0.02 0.03

VEL 0 0.06 0.19 0.38 0.55

WEI 0.03 0.01 0.34 0.30 1.00

SUB 1 2 3 4 5 6 7 8

WEI 0.00 0.05 0.00 0.02 0.05 0.14 1.00 0.00

END

Ecnomus sp. (total)'

DEP 0.11 0.21 0.40 0.61 0.81

WEI 0.22 0.92 1.00 0.62 0.20

VEL 0 0.06 0.19 0.38 0.55

WEI 0.49 0.37 0.38 1.00 0.17

SUB 1 2 3 4 5 6 7 8

WEI 0 0.26 0.00 0.40 0.17 1.00 0.17 0.65

END

Anisocentropus latifascia'

DEP 0.11 0.21 0.40 0.61 0.81

WEI 1.00 0.10 0.20 0.17 0.47

VEL 0 0.06 0.19 0.38 0.55

WEI 1.00 0.52 0.00 0.00 0.00

SUB 1 2 3 4 5 6 7 8

WEI 0.00 1.00 0.00 0.38 0.18 0.48 0.00 0.27

END

Marilia fusca'

DEP 0.11 0.21 0.40 0.61 0.81

```
WEI   0.35  0.03  0.04  0.00  1.00

VEL   0     0.06  0.19  0.38  0.55

WEI   1.00  0.00  0.32  0.00  0.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  1.00  0.00  0.27  0.00  0.03  0.00  0.00

END

Taschorema complex (total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.71  1.00  0.17  0.01  0.00

VEL   0     0.06  0.19  0.38  0.55

WEI   0.00  0.00  0.21  0.77  1.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.05  0.00  0.00  0.57  0.11  1.00  0.00

END

Cheumatopsyche sp.(total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   1.00  0.82  0.39  0.02  0.05

VEL   0     0.06  0.19  0.38  0.55

WEI   0.01  0.01  0.11  1.00  0.62

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.00  0.00  0.02  1.00  0.25  0.77  0.02

END

Oxythira mienica'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   1.00  0.95  0.43  0.17  0.05

VEL   0     0.06  0.19  0.38  0.55

WEI   0.07  0.03  1.00  0.44  0.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.87  0.00  0.17  0.33  0.96  1.00  0.17

END
```

```
Hellyethira sp. (total)'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.32  1.00  0.47  0.64  0.34
VEL   0     0.06  0.19  0.38  0.55
WEI   0.62  0.77  1.00  0.10  0.21
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.32  0.00  0.10  0.19  0.99  0.65  1.00
END
Notalina sp. (total)'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.89  1.00  0.40  0.48  0.10
VEL   0     0.06  0.19  0.38  0.55
WEI   0.40  0.30  1.00  0.50  0.50
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.14  0.00  0.09  0.06  1.00  0.30  0.55
END
Triplectides ciuskus ciuskus'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.00  0.21  0.35  0.07  1.00
VEL   0     0.06  0.19  0.38  0.55
WEI   1.00  0.38  0.00  0.00  0.00
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.72  0.00  0.75  1.00  0.50  0.00  0.00
END
Oecetis sp. (total)'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.44  0.66  1.00  0.48  0.84
VEL   0     0.06  0.19  0.38  0.55
WEI   0.29  0.25  0.45  1.00  0.05
SUB   1     2     3     4     5     6     7     8
```

```
WEI   0.00  0.19  0.00  1.00  0.56  0.37  0.60  0.50

END

Chironominae'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.03  0.40  1.00  0.38  0.11

VEL   0     0.06  0.19  0.38  0.55

WEI   0.74  0.54  1.00  0.10  0.34

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.09  0.00  1.00  0.14  0.39  0.12  0.36

END

Orthocladiinae'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.24  1.00  0.70  0.14  0.03

VEL   0     0.06  0.19  0.38  0.55

WEI   0.13  0.04  0.92  0.98  1.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.31  0.00  0.01  0.01  1.00  0.87  0.03

END

Tanypodoninae'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.17  0.64  1.00  0.03  0.25

VEL   0     0.06  0.19  0.38  0.55

WEI   0.44  0.16  1.00  0.07  0.03

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.06  0.00  0.92  0.26  0.35  1.00  0.03

END

Austrosimulium furiosum'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   1.00  0.46  0.03  0.07  0.00

VEL   0     0.06  0.19  0.38  0.55
```

```
WEI   0.02  0.00  0.18  1.00  0.52

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.17  0.00  0.00  1.00  0.03  0.63  0.00

END

Simsonia sp. (total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.73  1.00  0.02  0.11  0.07

VEL   0     0.06  0.19  0.38  0.55

WEI   0.03  0.06  0.74  1.00  0.67

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.04  0.00  0.18  1.00  0.55  0.71  0.18

END

Austrolimnius sp. (larv total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.35  0.17  1.00  0.17  0.05

VEL   0     0.06  0.19  0.38  0.55

WEI   0.42  0.07  0.02  1.00  0.32

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.16  0.00  0.03  0.31  1.00  0.30  0.04

END

Kingolus sp. (larv total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.66  1.00  0.70  0.02  0.00

VEL   0     0.06  0.19  0.38  0.55

WEI   0.01  0.00  1.00  1.00  0.04

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.21  0.00  0.00  0.50  1.00  0.08  0.00

END

Austrolimnius sp. (ad total)'

DEP   0.11  0.21  0.40  0.61  0.81
```

```
WEI   0.15  0.73  1.00  0.00  0.10

VEL   0     0.06  0.19  0.38  0.55

WEI   0.30  0.01  0.13  1.00  0.06

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.10  0.00  0.00  0.13  1.00  0.18  0.00

END

Kingolus sp. (ad total)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   1.00  0.14  0.65  0.00  0.00

VEL   0     0.06  0.19  0.38  0.55

WEI   0.02  0.00  0.06  1.00  0.06

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.02  0.00  0.00  1.00  0.39  0.09  0.00

END

Necterosoma sp. (larv)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.18  0.43  1.00  0.09  0.50

VEL   0     0.06  0.19  0.38  0.55

WEI   0.62  0.83  1.00  0.16  0.00

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.25  0.00  0.17  0.09  1.00  0.83  0.17

END
Sclerocyphon secretus (larv)'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.94  1.00  0.50  0.08  0.50

VEL   0     0.06  0.19  0.38  0.55

WEI   0.15  0.16  0.21  1.00  0.94

SUB   1     2     3     4     5     6     7     8

WEI   0.00  0.04  0.00  0.38  1.00  0.28  0.75  0.00

END

Micronecta sp. (total)'
```

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.21	0.35	1.00	0.70	0.11			
VEL	0	0.06	0.19	0.38	0.55			
WEI	1.00	0.81	0.06	0.09	0.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.03	0.00	1.00	0.04	0.23	0.02	0.63

END

Pisidium casertanum'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.62	0.73	0.91	0.09	1.00			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.86	0.04	1.00	0.32	0.06			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	1.00	0.00	0.38	0.02	0.36	0.75	0.05

END

Hydrobiidae sp. (total)'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.32	1.00	0.02	0.09	0.00			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.03	0.00	0.02	0.21	1.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.08	0.00	0.00	0.20	0.02	1.00	0.00

END

Planordidae sp. (total)'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.31	1.00	0.66	0.01	0.02			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.07	0.00	0.99	0.89	1.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.15	0.00	0.06	0.05	0.23	1.00	0.00

```
END
Paraleptamphopus sp.'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.11  0.09  0.85  1.00  0.39
VEL   0     0.06  0.19  0.38  0.55
WEI   1.00  0.87  0.15  0.00  0.00
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.66  0.00  1.00  0.22  0.20  0.09  0.33
END
Paracalliope sp.'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.25  1.00  0.15  0.55  0.26
VEL   0     0.06  0.19  0.38  0.55
WEI   0.10  0.39  1.00  0.09  0.06
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.24  0.00  0.11  0.12  0.50  1.00  0.69
END
Austrogammarus sp.'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.77  1.00  0.03  0.06  0.04
VEL   0     0.06  0.19  0.38  0.55
WEI   0.23  0.01  1.00  0.01  0.08
SUB   1     2     3     4     5     6     7     8
WEI   0.00  0.46  0.00  0.03  0.00  0.04  1.00  0.03
END
Austrochiltonia sp.'
DEP   0.11  0.21  0.40  0.61  0.81
WEI   0.39  0.26  1.00  0.26  0.08
VEL   0     0.06  0.19  0.38  0.55
WEI   1.00  0.40  0.93  0.66  0.10
```

```
SUB   1      2      3      4      5      6      7      8
WEI   0.00   0.49   0.00   1.00   0.18   0.54   0.30   0.42
END
Parataya australiensis'
DEP   0.11   0.21   0.40   0.61   0.81
WEI   0.62   0.09   1.00   0.27   0.06
VEL   0      0.06   0.19   0.38   0.55
WEI   1.00   0.29   0.00   0.01   0.00
SUB   1      2      3      4      5      6      7      8
WEI   0.00   0.30   0.00   1.00   0.06   0.19   0.00   0.21
END
Colubotelson sp.(total)'
DEP   0.11   0.21   0.40   0.61   0.81
WEI   1.00   0.25   0.01   0.06   0.00
VEL   0      0.06   0.19   0.38   0.55
WEI   0.79   0.00   0.06   0.03   1.00
SUB   1      2      3      4      5      6      7      8
WEI   0.00   0.46   0.00   0.00   0.00   1.00   0.76   0.00
END
Heterias sp (total)'
DEP   0.11   0.21   0.40   0.61   0.81
WEI   1.00   0.02   0.02   0.00   0.01
VEL   0      0.06   0.19   0.38   0.55
WEI   1.00   0.04   0.04   0.06   0.00
SUB   1      2      3      4      5      6      7      8
WEI   0.00   1.00   0.00   0.00   0.02   0.03   0.02   0.01
END
Turbellaria'
DEP   0.11   0.21   0.40   0.61   0.81
WEI   0.17   1.00   0.02   0.16   0.10
```

VEL	0	0.06	0.19	0.38	0.55			
WEI	0.05	0.04	0.22	0.13	1.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.13	0.00	0.06	0.17	0.19	1.00	0.01

END

Oligochaeta'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	1.00	0.74	0.69	0.48	0.36			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.63	0.62	0.83	0.96	1.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.91	0.00	0.94	0.94	0.70	1.00	0.75

END

Hydracarina'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.31	0.33	1.00	0.38	0.34			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.12	0.16	0.22	1.00	0.11			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.19	0.00	0.95	0.46	1.00	0.28	0.76

END

Austoaeschna sp. (total)'

DEP	0.11	0.21	0.40	0.61	0.81			
WEI	0.58	1.00	0.00	0.00	0.67			
VEL	0	0.06	0.19	0.38	0.55			
WEI	0.16	0.25	0.33	0.50	1.00			
SUB	1	2	3	4	5	6	7	8
WEI	0.00	0.00	0.00	0.00	1.00	0.60	1.00	0.00

END

Total Abundance'

```
DEP   0.11  0.21  0.40  0.61  0.81

WEI   0.53  0.84  1.00  0.29  0.15

VEL   0      0.06  0.19  0.38  0.55

WEI   0.57  0.27  1.00  0.79  0.99

SUB   1      2      3      4      5      6      7      8

WEI   0.00  0.41  0.00  0.69  0.30  0.60  1.00  0.30

END

Diversity'

DEP   0.11  0.21  0.40  0.61  0.81

WEI   1.00  0.99  0.90  0.79  0.77

VEL   0      0.06  0.19  0.38  0.55

WEI   0.89  0.68  0.98  1.00  0.82

SUB   1      2      3      4      5      6      7      8

WEI   0.00  0.93  0.00  0.83  0.83  1.00  0.94  0.71

END
```

Coal at Mt Bains - final RHYHAB habitat/hydraulic data.

```
BED DATA 'V' 'Si' 'S' 'F' 'G' 'C' 'B' 'Be'

0.0 'MtBains-T0' 9.29

GAU 9.34 0.389

GAU 9.37 0.569

SZF   9.132
0     -0.602      0     0     100   0     0     0     0     0     0
0.9   -0.322      0     0     100   0     0     0     0     0     0
3     -0.058      0     0     70    0     5     5     20    0     0
3.1   0     0     0     50    0     5     5     40    0     0
3.4   0.145 0.69534     0     0     0     20    20    60    0     0
3.7   0.165 0.48238     0     0     0     15    60    25    0     0
4     0.145 0.54926     0     0     0     15    70    15    0     0
4.4   0.141 0.81502     0     0     0     5     85    10    0     0
4.7   0.158 0.5827      0     0     0     15    80    5     0     0
5     0.12  0.81854     0     0     0     10    30    60    0     0
5.3   0.112 0.50174     0     0     0     10    30    60    0     0
5.7   0.102 0.92414     0     0     0     10    40    50    0     0
6.1   0.122 0.37502     0     0     0     0     40    60    0     0
6.5   0.139 0.81854     0     0     0     0     70    30    0     0
7     0.118 0.62142     0     0     0     0     70    30    0     0
7.6   0.065 0     0     80    0     0     0     20    0     0
7.85  0     0     0     80    0     0     0     20    0     0
8.1   -0.013      0     0     90    0     0     0     10    0     0
10.3  -0.22 0     0     100   0     0     0     0     0     0
```

```
12.4  -0.769      0     0     100   0     0     0     0     0     0
END
53.0 'MtBains-T1' 10.01

GAU 10.11 0.389

GAU 10.15 0.569

SZF   9.273
0     -0.935      0     0     100   0     0     0     0     0     0
1.6   -0.314      0     0     100   0     0     0     0     0     0

2.2   -0.1  0     0     100   0     0     0     0     0     0
2.5   0     0     0     100   0     0     0     0     0     0
3.6   0.101 0     0     100   0     0     0     0     0     0
4.35  0.245 0     0     100   0     0     0     0     0     0
5     0.407 0     0     0     50    45    5     0     0     0
5.4   0.485 0     0     0     50    45    5     0     0     0
5.8   0.545 0     0     0     40    45    15    0     0     0
6.1   0.612 0     0     0     40    45    15    0     0     0
6.5   0.682 0     0     0     55    30    10    5     0     0
6.9   0.724 0     0     0     50    5     40    5     0     0
7.3   0.737 0.072413333 0     0     15    10    70    5     0     0
7.7   0.752 0.112246667 0     0     0     10    60    30    0     0
8.1   0.842 0.14619     0     0     0     10    60    30    0     0
8.5   0.856 0.226056667 0     0     0     10    60    30    0     0
8.9   0.867 0.27797     0     0     0     10    60    30    0     0
9.4   0.85  0.246023333 0     0     0     10    60    30    0     0
9.8   0.867 0.048453333 0     20    0     0     60    20    0     0
9.85  0.269 0.112246667 0     20    0     15    45    20    0     0
10.3  0     0     0     100   0     0     0     0     0     0
10.9  -0.259      0     0     100   0     0     0     0     0     0
11.5  -0.279      0     0     100   0     0     0     0     0     0
END
82.0 'MtBains-T2' 10.68

GAU 10.89 0.389

GAU 10.92 0.569

SZF   9.722
0     -0.904      0     0     70    0     10    10    10    0     0
1.3   -0.529      0     0     50    0     20    20    10    0     0
2.4   -0.182      0     0     75    0     5     0     20    0     0
4     -0.201      0     0     100   0     0     0     0     0     0
4.6   -0.126      0     0     100   0     0     0     0     0     0
4.85  0     0     0     100   0     0     0     0     0     0
5.2   0.108 0     0     40    20    0     10    30    0     0
5.6   0.176 0     0     0     20    40    40    0     0     0
5.9   0.231 0     0     0     20    40    40    0     0     0
6.3   0.338 0.042463333 0     0     20    40    40    0     0     0
6.7   0.442 0.09238     0     20    20    60    0     0     0     0
7     0.514 0.11634     0     0     0     20    70    10    0     0
7.4   0.646 0.12233     0     0     0     20    70    10    0     0
7.8   0.763 0.108353333 0     0     0     10    30    60    0     0
8.1   0.856 0.100366667 0     0     0     0     20    80    0     0
8.45  0.958 0.100366667 0     0     0     0     20    80    0     0
8.7   1.023 0.09238     0     60    0     10    20    10    0     0
9     1.064 0.088386667 0     80    0     10    0     10    0     0
9.5   1.061 0.05045     0     100   0     0     0     0     0     0
9.7   0.924 0.072413333 0     100   0     0     0     0     0     0
```

```
9.9   0.794 0.07441     0     100   0     0     0     0     0     0
10.1  0.438 0.05644     0     100   0     0     0     0     0     0
10.4  0.496 0.070416667 0     100   0     0     0     0     0     0
11    0     0     0     100   0     0     0     0     0     0
11.3  -0.271      0     0     100   0     0     0     0     0     0
12    -1.071      0     0     100   0     0     0     0     0     0
END
112.5 'MtBains-T3' 11.76

GAU 11.82 0.389

GAU 11.87 0.569

SZF   11.575
0     -1.183      0     0     45    0     10    25    20    0     0
2     -0.935      0     0     0     0     10    60    30    0     0
3     -0.811      0     0     0     5     55    15    25    0     0
3.7   -0.534      0     0     0     15    55    15    15    0     0
4     -0.378      0     0     0     10    10    60    20    0     0
5.7   -0.115      0     0     0     0     0     10    90    0     0
7.45  -0.023      0     0     90    0     0     0     10    0     0
7.8   0     0     0     100   0     0     0     0     0     0
8.45  0.072 0     0     60    0     0     10    30    0     0
8.7   0.115 0.51582     0     0     0     10    20    70    0     0
9     0.11  0.71998     0     0     0     10    30    60    0     0
9.3   0.089 0.6795      0     0     0     15    45    40    0     0
9.6   0.119 0.70238     0     0     0     20    50    30    0     0
9.9   0.144 0.64254     0     0     0     20    50    30    0     0
10.2  0.147 0.5915      0     0     0     10    80    10    0     0
10.45 0.147 0.67774     0     0     0     15    85    0     0     0
10.7  0.165 0.9171      0     0     0     10    80    10    0     0
11    0.169 0.6795      0     0     0     10    30    60    0     0
11.3  0.17  0.81678     0     0     0     0     30    70    0     0
11.6  0.197 0.84846     0     0     0     0     20    80    0     0
12    0.185 0.75518     0     0     0     0     20    80    0     0
12.6  0.132 0     0     0     0     90    10    0     0     0
13.2  0     0     0     70    0     30    0     0     0     0
13.45 -0.3  0     0     100   0     0     0     0     0     0
15.2  -0.567      0     0     100   0     0     0     0     0     0
16.2  -0.601      0     0     100   0     0     0     0     0     0
END
201.2 'MtBains-T4' 12.55

GAU 12.82 0.389

GAU 12.90 0.569

SZF   11.898
0     -0.934      0     0     100   0     0     0     0     0     0
0.6   -1.678      0     0     100   0     0     0     0     0     0
0.75  -1.488      0     0     100   0     0     0     0     0     0
0.9   -1.431      0     0     100   0     0     0     0     0     0
1.15  -1.081      0     0     100   0     0     0     0     0     0
1.85  -0.92 0     0     100   0     0     0     0     0     0
2.1   -0.541      0     0     100   0     0     0     0     0     0
3.3   -0.155      0     0     100   0     0     0     0     0     0
4.4   -0.026      0     0     100   0     0     0     0     0     0
4.52  0     0     0     100   0     0     0     0     0     0
4.75  0.083 0     0     100   0     0     0     0     0     0
5.2   0.213 0.269983333 0     95    0     5     0     0     0     0
5.5   0.264 0.299933333 0     95    0     5     0     0     0     0
```

```
5.75  0.407 0.279966667 0     95    0     5     0     0     0     0
6     0.427 0.275973333 0     90    0     5     5     0     0     0
6.2   0.429 0.256006667 0     95    0     5     0     0     0     0
6.45  0.447 0.24203     0     95    0     5     0     0     0     0
6.7   0.441 0.232046667 0     95    0     5     0     0     0     0
6.9   0.465 0.214076667 0     95    0     5     0     0     0     0
7.05  0.475 0.166156667 0     95    0     5     0     0     0     0
7.15  0.637 0.13421     0     95    0     5     0     0     0     0
7.4   0.652 0.15817     0     100   0     0     0     0     0     0
7.7   0.611 0.148186667 0     80    5     10    5     0     0     0
8     0.554 0.108253333 0     80    5     10    5     0     0     0
8.3   0.487 0     0     85    0     15    0     0     0     0
8.9   0.287 0     0     80    0     10    10    0     0     0
9.3   0.056 0     0     100   0     0     0     0     0     0
9.75  0     0     0     100   0     0     0     0     0     0
10.3  -0.051      0     0     100   0     0     0     0     0     0
11.1  -0.261      0     0     100   0     0     0     0     0     0
13    -0.386      0     0     100   0     0     0     0     0     0
15    -0.603      0     0     100   0     0     0     0     0     0
16    -0.797      0     0     100   0     0     0     0     0     0
END
282.2 'MtBains-T5' 13.64

GAU 13.67 0.389

GAU 13.71 0.569

SZF   13.523
0     -1.281      0     0     100   0     0     0     0     0     0
1.9   -0.852      0     0     100   0     0     0     0     0     0
3.4   -0.546      0     0     100   0     0     0     0     0     0
3.5   -0.435      0     0     100   0     0     0     0     0     0
4     -0.347      0     0     100   0     0     0     0     0     0
4.25  -0.005      0     0     100   0     0     0     0     0     0
4.3   0     0     0     40    0     10    5     45    0     0
4.6   0.133 0.91  0     20    0     0     40    40    0     0
5     0.092 0.78  0     0     0     0     30    70    0     0
5.4   0.117 0.89  0     0     0     0     30    70    0     0
5.75  0.115 0.57  0     0     0     5     15    80    0     0
6.1   0.073 0.44  0     0     0     10    10    70    10    0
6.45  0.106 0.14  0     0     0     70    20    0     10    0
6.9   0.096 0.49  0     0     0     15    10    75    0     0
7.4   0.097 0.37  0     0     0     5     55    40    0     0
7.9   0.082 0.44  0     0     0     0     50    50    0     0
8.5   0.106 0.4   0     0     0     0     30    70    0     0
9     0.08  0.32  0     0     0     0     30    70    0     0
9.6   0.12  0.46  0     0     0     0     40    60    0     0
10.25 0.11  0.12  0     0     0     10    30    50    10    0
10.6  0.033 0.25  0     0     0     0     10    70    20    0
11.1  0.025 0.23  0     0     0     0     10    70    20    0
11.6  0.075 0.44  0     0     0     0     20    80    0     0
12.05 0.063 0.21  0     0     0     0     40    60    0     0
12.35 0.055 0     0     0     0     0     80    20    0     0
13    0.051 0     0     0     0     0     20    80    0     0
13.7  0     0     0     100   0     0     0     0     0     0
14.2  -0.067      0     0     100   0     0     0     0     0     0

17    -0.1  0     0     100   0     0     0     0     0     0
18.9  -0.582      0     0     100   0     0     0     0     0     0
21.4  -1.387      0     0     100   0     0     0     0     0     0
END
```

```
313.9 'MtBains-T6' 13.68

GAU 13.74 0.389

GAU 13.83 0.569

SZF   13.18
0     -2.259      0     0     100   0     0     0     0     0     0
1.3   -2.004      0     0     100   0     0     0     0     0     0
1.7   -1.804      0     0     100   0     0     0     0     0     0
2.5   -1.526      0     0     100   0     0     0     0     0     0
2.85  -1.069      0     0     100   0     0     0     0     0     0
3.3   -0.576      0     0     100   0     0     0     0     0     0
3.45  0     0     0     100   0     0     0     0     0     0
3.6   0.329 0     0     100   0     0     0     0     0     0
3.8   0.478 0     0     100   0     0     0     0     0     0
4.3   0.67  0     0     100   0     0     0     0     0     0
4.7   0.851 0     0     50    0     40    10    0     0     0
5     0.868 0.01  0     100   0     0     0     0     0     0
5.5   0.921 0.01  0     80    0     0     0     20    0     0
6     0.889 0.01  0     30    0     40    30    0     0     0
6.5   0.849 0.01  0     20    0     0     70    10    0     0
7     0.828 0.02  0     0     0     30    40    20    10    0
7.5   0.786 0.02  0     10    0     40    30    20    0     0

8     0.777 0.02  0     10    0     40    30    20    0     0
8.5   0.774 0.03  0     10    0     40    30    20    0     0
9     0.747 0.04  0     10    0     20    20    40    10    0
9.5   0.739 0.03  0     10    0     40    30    20    0     0
10    0.705 0.03  0     10    0     40    30    20    0     0
11    0.588 0.05  0     0     0     40    50    10    0     0
11.5  0.549 0.05  0     0     0     60    30    10    0     0
12    0.504 0.03  0     0     0     50    40    10    0     0
12.3  0.498 0.04  0     0     0     50    40    10    0     0
12.9  0.421 0.01  0     40    0     20    40    0     0     0
13.7  0.252 0.01  0     40    0     20    40    0     0     0
14.7  0.139 0     0     100   0     0     0     0     0     0
15.6  0     0     0     100   0     0     0     0     0     0
16.4  -0.104      0     0     100   0     0     0     0     0     0
18.4  -0.677      0     0     100   0     0     0     0     0     0
END
332.7 'MtBains-T7' 14.70

GAU 14.76 0.389

GAU 14.85 0.569

SZF   14.2
0     -2.247      0     0     100   0     0     0     0     0     0
0.7   -2.089      0     0     100   0     0     0     0     0     0
0.8   -1.958      0     0     100   0     0     0     0     0     0
2.2   -1.567      0     0     100   0     0     0     0     0     0
2.5   -1.019      0     0     100   0     0     0     0     0     0
3     -0.406      0     0     50    0     0     0     0     0     50
3.02  0     0     0     50    0     0     0     0     0     50
3.3   0.136 0.01  0     10    0     0     0     0     0     90
3.5   0.307 0     0     0     0     0     0     0     0     100
3.9   0.534 0     0     50    0     0     0     0     0     50
4.1   0.819 0     0     50    0     0     0     0     0     50
5.1   1.061 0     0     100   0     0     0     0     0     0
6     1.064 0     0     80    0     0     10    10    0     0
```

```
7     1.091 0     0     40    0     0     60    0     0     0
8     1.035 0     0     25    0     0     60    15    0     0
9     1.042 0     0     20    0     0     70    10    0     0
10    1.029 0.01  0     15    0     0     75    10    0     0
11    1.117 0.02  0     10    0     0     90    0     0     0
12    1.104 0.02  0     10    0     0     85    5     0     0
13    1.099 0.02  0     20    0     20    60    0     0     0
14    1.036 0     0     50    0     0     50    0     0     0
14.4  0.833 0     0     10    0     20    20    0     0     50
14.7  0.576 0     0     10    0     20    20    0     0     50
14.85 0.247 0     0     50    0     0     0     0     0     50
15    0     0     0     80    0     0     0     0     0     20
15.2  -0.331      0     0     80    0     0     0     0     0     20
16    -1.133      0     0     100   0     0     0     0     0     0
END
392.7 'MtBains-T8' 16.01

GAU 16.07 0.389

GAU 16.16 0.569

SZF   15.51
0     -1.921      0     0     100   0     0     0     0     0     0
1.9   -1.598      0     0     100   0     0     0     0     0     0
2.17  -1.468      0     0     100   0     0     0     0     0     0
2.4   -1.035      0     0     100   0     0     0     0     0     0
4.42  -0.125      0     0     100   0     0     0     0     0     0
4.46  0     0     0     100   0     0     0     0     0     0
5.1   0.356 0.02  0     100   0     0     0     0     0     0
6     1.025 0     0     60    0     0     40    0     0     0
7     1.163 0.01  0     40    0     0     60    0     0     0
8     1.224 0.01  0     30    0     0     70    0     0     0
9     1.14  0.02  0     10    0     0     90    0     0     0
10    1.08  0.02  0     10    0     0     90    0     0     0
11    1.065 0.02  0     10    0     0     80    10    0     0
12    1.038 0.03  0     10    0     15    70    5     0     0
13    1.14  0.03  0     10    0     20    60    10    0     0
14    1.265 0     0     10    0     20    60    0     0     10
14.4  1.201 0     0     10    0     10    30    0     0     50
14.6  0.453 0     0     5     0     5     20    0     0     70
14.8  0.211 0     0     0     0     0     0     0     0     100
15    0     0     0     30    0     0     0     20    0     50
15.7  -0.648      0     0     100   0     0     0     0     0     0
16    -0.946      0     0     100   0     0     0     0     0     0
END
432.7 'MtBains-T9' 18.68

GAU 18.70 0.389

GAU 18.73 0.569

SZF   18.343
0     -0.24 0     0     100   0     0     0     0     0     0
0.6   -0.296      0     0     90    0     0     10    0     0     0
1.1   -0.213      0     0     50    0     0     30    20    0     0
1.46  -0.041      0     0     40    0     0     10    50    0     0
1.53  0     0     0     40    0     0     10    50    0     0
1.8   0.035 0.05  0     10    0     0     50    40    0     0
2     0.122 0.09  0     10    0     0     50    40    0     0
2.4   0.124 0.38  0     0     0     0     60    30    10    0
2.7   0.212 0.43  0     0     0     0     25    25    50    0
```

```
2.8   0.074 0.43  0     0     0     0     10    10    80    0
3.1   0.119 0.35  0     0     0     0     10    10    80    0
3.12  0.259 0.39  0     0     0     40    10    0     50    0
3.5   0.261 0.56  0     0     0     30    30    30    0     10
4     0.21  0.45  0     0     0     0     10    10    80    0
4.2   0.242 0.15  0     0     0     0     10    10    80    0
4.25  0.106 0.32  0     0     0     0     0     0     100   0
4.45  0.168 0.52  0     0     0     0     0     0     100   0
4.66  0.133 0.44  0     0     0     0     0     0     100   0
4.8   0.311 0.33  0     0     0     30    0     30    40    0
5     0.337 0.49  0     0     0     60    0     30    10    0
5.28  0.324 0.47  0     0     0     0     0     50    50    0
5.6   0     0     0     0     0     0     0     0     100   0
6.03  -0.219      0     0     0     0     0     0     0     100   0
6.15  0     0     0     0     0     20    0     0     80    0
6.28  0.033 0     0     0     0     40    0     0     60    0
6.36  0     0     0     50    0     0     0     0     50    0
6.71  -0.081      0     0     40    0     0     0     10    50    0
6.96  0     0     0     0     0     0     0     40    60    0
7.03  0.071 0.04  0     0     0     0     0     40    60    0
7.35  0.064 0     0     0     0     0     30    20    50    0
7.37  0     0     0     0     0     0     30    20    50    0
7.68  -0.122      0     0     20    0     0     0     20    60    0
9.6   -0.169      0     0     40    0     0     0     10    50    0
9.9   -0.212      0     0     20    0     10    0     0     70    0
10.9  -0.801      0     0     20    0     0     20    0     60    0
END
END
```

Coal at Mt Bains - Habitat preference data.

```
Nousia sp. (total)'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.95  0.36  0.01  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.00  0.01  0.17  0.22  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.02  0.00  0.01  1.00  0.32  0.55  0.00
END
Atalophlebia sp.'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.00  0.11  1.00  0.77  0.08  0.09
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.31  0.08  0.06  1.00  0.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.17  0.00  0.08  0.05  0.08  1.00  0.00
END
Tasmanocoenis sp.(total)'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.41  0.02  0.10  1.00  0.13  0.53
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   1.00  0.82  0.06  0.04  0.01  0.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.51  0.00  0.24  0.27  0.01  0.01  1.00
END
Lingora aurata'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.17  1.00  0.33  0.00  0.00  0.01
```

```
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.01  0.01  0.07  0.53  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.01  0.00  0.04  1.00  0.53  0.84  0.00
END
Ecnomus sp.Type 2'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.29  0.17  0.28  1.00  0.44  0.12
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.29  0.20  0.58  1.00  0.18  0.05
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  1.00  0.00  0.07  0.44  0.45  0.11  0.37
END
Helicopsyche murrumba'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.57  1.00  0.20  0.02  0.01  0.01
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.01  0.15  0.55  0.26  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.02  0.00  0.34  0.77  1.00  0.45  0.01
END
Taschorema complex (total)'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.26  1.00  0.27  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.19  0.08  0.15  0.28  0.43  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.38  0.07  1.00  0.31  0.17
END
Ulmerochorema sp. (total)'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.53  0.64  1.00  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.00  0.00  0.25  1.00  0.50
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.00  0.24  0.30  1.00  0.00
END
Cheumatopsyche sp.(total)'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.13  0.06  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.00  0.02  0.09  0.09  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.04  1.00  0.24  0.19  0.00
END
Oecetis sp.'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.00  0.80  0.10  1.00  0.37  0.50
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.18  0.30  0.12  1.00  0.61  0.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.69  0.00  0.00  0.20  1.00  0.00  0.20
END
Chironominae '
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.19  0.47  0.34  1.00  0.56  0.92
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.03  0.44  0.71  0.67  1.00  0.04
```

```
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  1.00  0.00  0.06  0.49  0.82  0.65  0.04
END
Orthocladiinae'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.85  0.37  0.04  0.02  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.01  0.02  1.00  0.74  0.60
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.08  0.00  0.00  0.28  1.00  0.39  0.00
END
Tanypodoninae'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.28  0.60  0.50  1.00  0.17  0.92
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.16  0.97  0.13  1.00  0.80  0.08
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.52  0.00  0.20  0.46  0.92  1.00  0.15
END
Austrosimulium furiosum'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.63  0.07  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.01  0.01  0.14  0.10  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.06  0.62  1.00  0.15  0.00
END
Austrosimulium sp. (pupae.)'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.82  0.02  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.00  0.09  0.03  1.00  0.88
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.18  0.69  1.00  0.04  0.00
END
Pisidium casertanum'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.22  0.95  0.05  0.10  0.32  1.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.01  0.41  1.00  0.29  0.36  0.27
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.27  0.00  1.00  0.53  0.57  0.08  0.02
END
Rivisessor gunnii'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.54  1.00  0.17  0.01  0.01  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.01  1.00  0.01  0.22  0.37
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  1.00  0.14  0.06  0.13  0.00
END
Physa acuta'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.97  1.00  0.33  0.21  0.02  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.03  0.06  0.10  0.77  1.00  0.10
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.05  0.00  0.11  0.00  1.00  0.33  0.02
END
```

```
Austrochiltonia australis'

DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.10  0.02  0.04  1.00  0.09  0.01
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.56  1.00  0.01  0.20  0.05  0.02
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  1.00  0.00  0.13  0.01  0.19  0.07  0.57
END
Colubotelson sp.'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.77  0.41  0.00  0.05  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.24  1.00  0.51  0.05  0.30
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  1.00  0.10  0.25  0.04  0.00
END
Turbellaria'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.30  0.20  1.00  0.00  0.00  0.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.00  0.00  0.10  1.00  0.26
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.00  0.00  0.00  0.11  0.10  1.00  0.00
END
Oligochaeta'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.05  1.00  0.63  0.55  0.25  0.76
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.06  1.00  0.19  0.08  0.82  0.83
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.33  0.00  1.00  0.67  0.59  0.05  0.05
END
Hirudinea sp.'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   1.00  0.60  0.00  0.75  0.00  0.15
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.00  0.36  0.00  0.38  0.50  1.00
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.27  0.00  0.00  0.32  1.00  0.00  0.00
END
Total Abundance'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.13  0.41  0.78  1.00  0.10  0.14
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.17  0.59  0.45  1.00  0.19  0.31
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00

WEI   0.00  0.74  0.00  0.43  0.77  1.00  0.22  0.63
END
Diversity'
DEP   0.10  0.17  0.26  0.41  0.66  1.00
WEI   0.52  0.79  0.65  0.11  0.47  1.00
VEL   0.00  0.03  0.11  0.21  0.36  0.68
WEI   0.76  0.78  0.61  1.00  0.59  0.86
SUB   1.00  2.00  3.00  4.00  5.00  6.00  7.00  8.00
WEI   0.00  0.79  0.00  0.73  0.74  0.84  0.59  1.00
END
```